CUNNINGHAMIA

VOLUME 1 (3)
1985

ROYAL BOTANIC GARDENS, SYDNEY
National Herbarium of New South Wales

CUNNINGHAMIA

ROYAL BOTANIC GARDENS, SYDNEY

Ecological contributions from the National Herbarium of New South Wales

Vol. 1 (3) 1985

ISSN 0727-9620

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General Editor: A.S. Mitchell
Scientific Editor: J.M. Powell

Cunninghamia 1(3), 285–311 (1985)

NATURAL VEGETATION AND SETTLEMENT AT MACQUARIE PASS, ILLAWARRA REGION, NEW SOUTH WALES

H. Fallding & J. S. Benson*

(Accepted for publication 29.7.1983)

ABSTRACT

Fallding, H. & Benson, J. S. (National Herbarium of New South Wales, Royal Botanic Gardens, Sydney, New South Wales, Australia 2000) 1985. Natural vegetation and settlement at Macquarie Pass, Illawarra region, New South Wales. Cunninghamia 1(3), 285–311. The plant communities of the Macquarie Pass area on the Illawarra escarpment, 100 km south of Sydney, are described and mapped; their distribution reflects geology, climate and topography. Open-forest, woodland, shrub communities and sedgelands occur on the plateau. The escarpment is characterized by closed-forest and tall open-forest; the foothills and coastal plain by drier open-forest and woodland communities. Four hundred and forty-one species are recorded. Comments are made on the rainforests of the Illawarra region and the effects of settlement on the vegetation of the escarpment and the coastal plain. The original extent of rainforest on the Illawarra is considered to be less than that often assumed.

INTRODUCTION

The subtropical rainforests and moist eucalypt forests of the Illawarra escarpment have interested botanists since Allan Cunningham in 1818 first entered "within the dark shades of a tropical forest, composed of very lofty timber of the red cedar [*Toona australis*], *Tristania albens* or Turpentine Tree [*Syncarpia glomulifera*]; large *Eucalypti*, of the species called Blue Gum, and many other trees . . . the whole being bound together with immense scandent and volubilous plants, that cannot fail to arrest the attention and admiration of the most indifferent observer" (quoted in Lee, 1925).

Botanical work in the Illawarra, a region extending from Bulli, 30 km north of Macquarie Pass, southward to the Shoalhaven River, includes that of Moore & Betche (1893), Hamilton (1914), Davis (1936, 1941a, b), Pidgeon (1940), Hume (1969), Strom (1977), Bywater (1978) and Fuller (1980). However, most of this work has been confined to the northern end, particularly around Bulli Pass and Mount Kiera. Little work has been done in the Macquarie Pass region or further south.

In this study the vegetation within and surrounding Macquarie Pass National Park is described and mapped. It embraces a transect of the Illawarra escarpment from exposed heath on the sandstone plateau through rainforest and moist eucalypt forest on the escarpment itself, to the drier open-forest and woodland on the coastal plain. This area was recognized for its natural and scenic beauty as early as 1882, when three reserves, about 200 ha in area, were set aside for the preservation of timber and recreation.

THE STUDY AREA

Macquarie Pass National Park (1064 ha) is about 100 km south of Sydney on the Illawarra escarpment, between the townships of Robertson (34° 35′S, 150° 36′E, 750 m alt.) on the Wingecarribee Tableland and Albion Park (34° 35′S, 150° 47′E,

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10 m alt.) on the Illawarra coastal plain (see map in back pocket). It lies within the "horseshoe" of sandstone cliffs formed by the escarpment around the head of the basin drained by Macquarie Rivulet, one of the largest streams in the region (Figure 1). The Park is bounded to the north by Johnsons Ridge, which runs eastwards from the escarpment onto the coastal plain between Marshall Mount and Albion Park. The area is a small part of a more-or-less continuous band of natural vegetation stretching along the Illawarra escarpment. It is bounded on both the eastern and western sides by cleared land, at present used for dairying, potato cropping and beef production. The Illawarra Highway cuts through the middle of Macquarie Pass National Park, linking the agricultural lands of the coast and the highlands. The Park is also traversed by power lines. Most of the eastern part of Johnsons Ridge is privately owned farmland, with dairying and cropping on the river flats and grazing in the foothills of the escarpment and on clearings on the ridge itself. Some forest remains, mainly on the steeper slopes of the ridge, and it becomes quite extensive at higher altitudes. On the tableland, to the north and north-west of Macquarie Pass, are the Avon, Cordeaux and Nepean Dam catchments. These are virtually undisturbed bushland, and are managed by the Metropolitan Water Sewerage and Drainage Board (M.W.S.D.B.).

Geology, topography and soils

The geology of the study area is illustrated in Figure 2 and a cross-section through Macquarie Pass showing the relationships between geology, topography and vegetation is included on the map sheet (in back pocket). The geological nomenclature used throughout this paper is that of Bowman (1974). However, it should be noted that Carr (1983) has reclassified some of the strata.

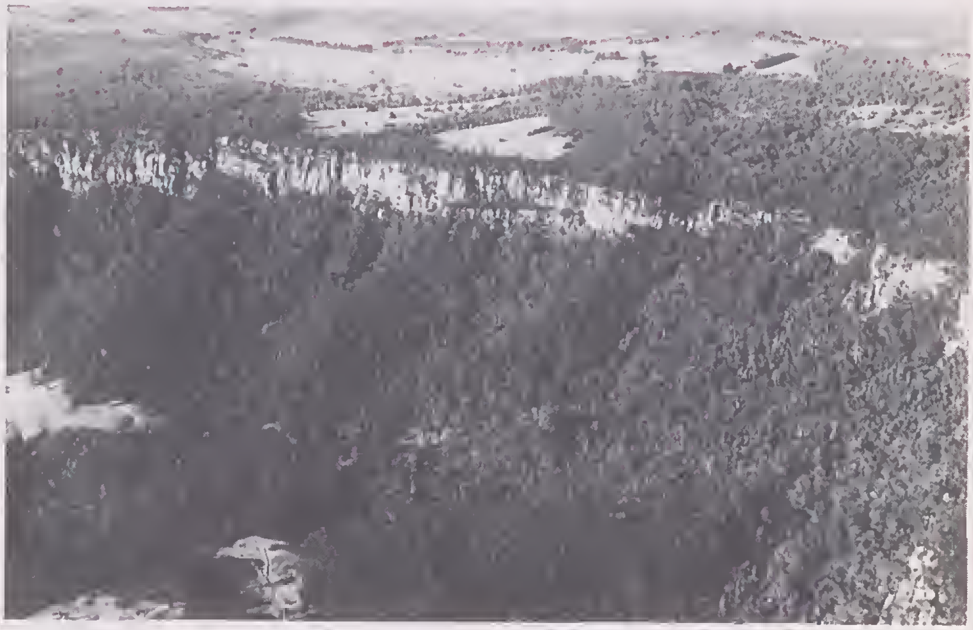

Figure 1. View over the southern half of Macquarie Pass National Park looking south-west over the upper part of Macquarie Rivulet, showing part of the horseshoe of sandstone cliffs, cleared areas on the Robertson Plateau, and part of two cleared areas on a latite bench. Rainforest can be seen in the gullies below the cliff-line and tall open-forest on the ridges. The vegetation remaining on the plateau is predominantly open-forest on Wianamatta Shale.

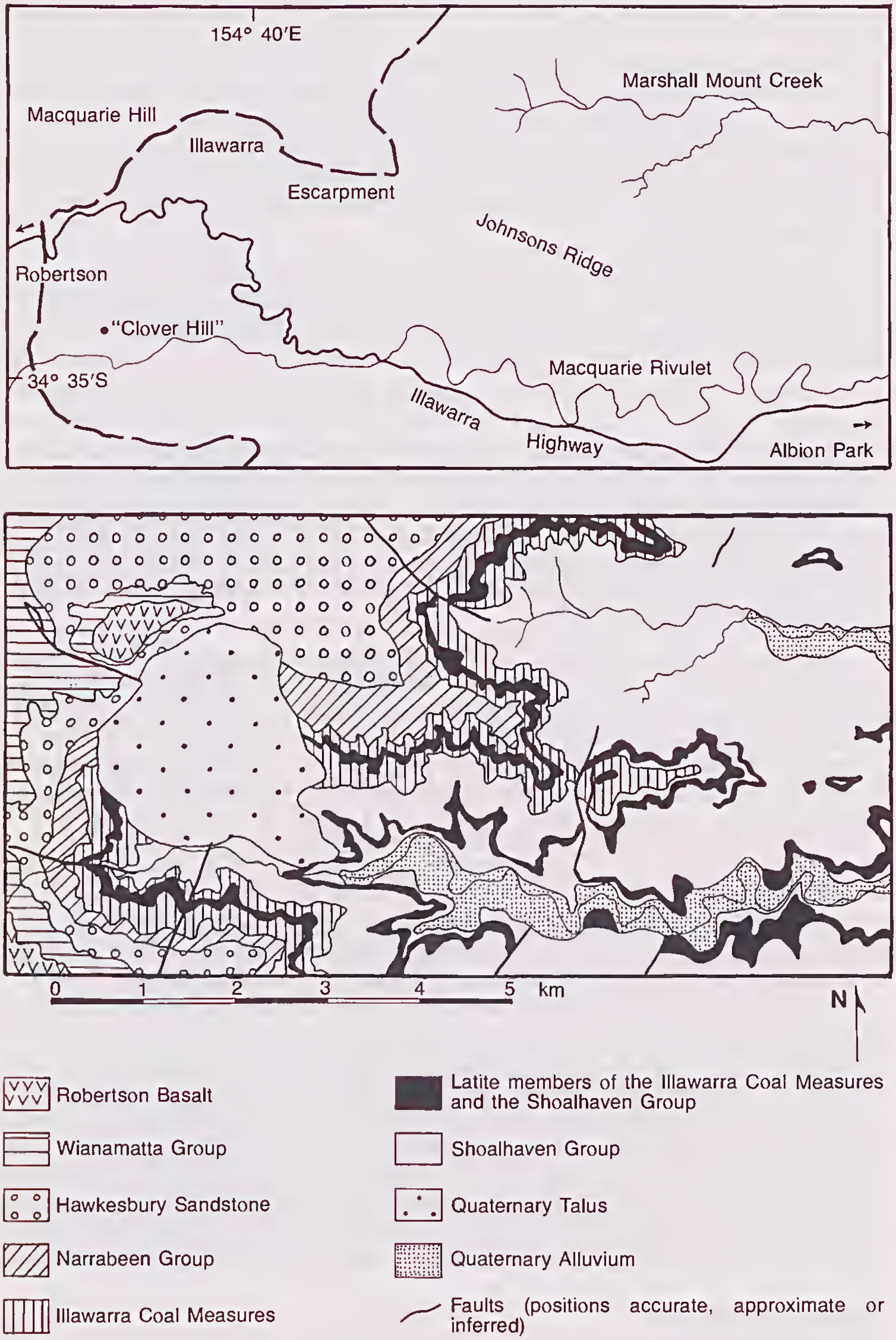

Figure 2. Major features and geology of the study area. Geology after Bowman (1974).

The uppermost rock unit is the Robertson Basalt (Tertiary age), outcropping at Macquarie Hill (Bowman, 1974). The Wianamatta Group (predominantly Triassic mudrock) lies below this, surrounding the outcropping basalt at Macquarie Hill, and also occurring extensively on the plateau to the south. The major part of the plateau and the cliffs dominating the escarpment are of Hawkesbury Sandstone (Triassic). The upper part of Johnsons Ridge is of Narrabeen Group units (sandstone and claystones) in the Clifton Sub-group. Below this, on the flanks of the ridge and the foothills of the escarpment generally, there are early Late Permian rocks of the Illawarra Coal Measures and the Shoalhaven Group, a number of latite members and the Budgong Sandstone.

Much of the head of the gully at Macquarie Pass consists of large and deep Quaternary talus deposits. The southern parts of the gully and Johnsons Ridge, however, are made up of sedimentary strata of the Narrabeen Group, Illawarra Coal Measures and the Shoalhaven Group.

A number of topographic units can be distinguished — plateau top, cliffs, escarpment slopes and benches, foothill spurs and gullies, and the coastal plain. Drainage patterns on the plateau and escarpment are dendritic, with local variations due to faulting or jointing. Where topography is gentle, streamflow is less definite and sometimes impeded. Johnsons Ridge is the watershed between the catchments of Macquarie Rivulet to the south and Marshall Mount Creek to the north. The Macquarie Rivulet, which originates on the Robertson Basalt on agricultural land, flows through Wianamatta Shale and Hawkesbury Sandstone before plunging over the cliff-line at Macquarie Falls.

Soil structure and composition are closely related to parent rock material and to topographic position. On the plateau, krasnozems are derived from the basalt outcrops; uniform to duplex soils develop from Wianamatta Shale and Hawkesbury Sandstone; podzols form in the shallow, sandy, swampy depressions. On the talus slopes the soils range in structure from uniform earthy sands at the top of the deposit, to yellow duplex soils in the lower parts. Soils on the escarpment are otherwise mainly a variety of duplex types that reflect differences in parent material.

Climate

The Illawarra experiences a mild climate with warm moist summers, cool winters and no marked dry season. In summer, the prevailing winds are from the south (SSW) or north-east and are often rain-bearing. In winter, dry winds come from the west or south-west. The escarpment causes uplift of air masses and consequent orographic rainfall and mists. Thus, rainfall on the edge of the plateau (for example, at Robertson, 1650 mm annually) is higher than that on the coastal plain (for example, at Albion Park, 1089 mm annually; Bureau of Meteorology, 1979). Macquarie Pass receives an annual rainfall of more than 1600 mm (from rainfall map by Young & Johnson, 1977). Funnelling associated with gorges and ravines can cause still higher local rainfalls on the upper slopes of the escarpment (Fuller, 1980). Temperatures in the region are affected by altitude and proximity to the sea. July mean minimum temperatures range from 3°C at Robertson to about 6°C at Albion Park; January mean maximum temperatures are about 25°C on both the coast and escarpment.

History of settlement

Other than the use of the Pass as a route between the highlands and the coast, there are no details of Aboriginal use in the area. The first Europeans to come to the region were the cedar-getters in the early 1800s. In 1821, one such man described the vegetation of the region as being "except for small open patches, covered with timber and almost impenetrable". Others described the Macquarie Rivulet flats as being covered "with tall cabbage-tree palm [*Livistona australis*], ferns, cedar [*Toona australis*] and creeping vines" (Bayley, 1959). Harvesting of cedar continued for about 50 years, until the supply was exhausted.

Early land grants went to J.T. Hughes, C.T. Smith and Henry Osborne (about 1820). The landholders leased 30 to 40 acre (12 to 16 ha) blocks to immigrant settlers who agreed to clear the land in return for six years free rent. The large holdings were later subdivided (for example, Hughes' "Albion Park" in 1860, and the Marshall Mount Estate in 1890) into 40 and 60 acre (16 and 24 ha) blocks that were sold mainly to tenants. Such sales resulted in ". . . quick progress along the Macquarie. Timber was felled, properties fenced with hardwood and hut building proceeded as fast as the sawyers could cut hardwood into planks. A great quantity of firewood was despatched by rail for the Sydney market" (Bayley, 1959). Most of the area of Macquarie Pass National Park was divided into 40 and 60 acre portions that were surveyed during the period 1856 to 1906.

Hardwood logging and clearing probably first extended onto the escarpment in the 1840s and 1850s. The more fertile latite bands are likely to have been cleared first. After clearing, the land was generally cropped with wheat, corn or potatoes, and cattle were grazed. Butter, eggs, fowls and pigs were shipped to Sydney markets (Bayley, 1959). Wheat was grown in the area until 1860 when infestation by rust halted its cultivation. An idea of the degree of clearing can be gained from A. McFarland (1872) a travelling judge, who described the escarpment behind Lake Illawarra: "From the sea to the mountain — ay — far up the mountain sides, and occasionally to the very summits, pasture farms cover the face of the country; grass, grass, everywhere; on every flat, hill, and dale, in every nook and cranny. But, as a rule, the tillage or state of Agriculture is poor; but little corn or other grain is raised; there is a large supply of ugly 'stump' — redeemed in part by occasional clumps of cedars, and cabbage trees, belts of forest, and sylvan glades".

Dairying increased in prominence after the 1840s with the development of refrigeration, and wheat production declined. There were three butter factories between the bottom of Macquarie Pass and Albion Park (Bob Dalhunty, pers. comm.). However, Bayley (1959) reports that "In the 1880s Shellharbour and Macquarie River settlers began moving to the Richmond River . . .". During this century the local population and the dairy industry have declined greatly, some land has been abandoned to regrowth, and beef cattle grazing has become more important.

A well-worn bridle track existed down Macquarie Pass by 1878 and settlers were keen for a road to be constructed. In 1898 the Macquarie Pass road was opened. The road attracted many tourists in the 1920s and 30s and was sealed in 1932. Many ferns and wildflowers were picked during the 1920s. A.G. Hamilton (1914) mentions that the giant maidenhair fern *Adiatum affine (A. silvaticum)* "is gathered in quantities, tied in bundles and exported to Germany, where it is dyed with anilin green and re-exported to Australia for decorative purposes". Increasing areas of land were reserved for public recreation and the protection of native flora and fauna from 1882 to 1974 when Macquarie Pass National Park was dedicated.

Recent disturbances have come from power lines that were constructed in the late 1950s, and bisect the National Park with a band of cleared land; and a wildfire that swept much of the escarpment in 1968. The Macquarie Pass road (the Illawarra Highway) is carrying increasing volumes of traffic, but still retains its appeal to the tourist.

THE VEGETATION

Survey methods

Familiarity with the area was gained from field work in 1979 and a survey of the literature. Plant communities are defined in terms of structure (Specht, 1970) and floristics. Field sampling was either by ground traverse, where general species lists were compiled, or by sample sites where cover ratings for trees (using 40 m × 10 m quadrats) and cover-abundance ratings for understorey species (using 10 m × 10 m quadrats) were assessed, tree diameters measured, and slope, aspect, geology, geomorphology and any disturbance were recorded. Sample sites were not placed in communities 4a, 4b, 4c, 8 or 9, these being sampled only by ground traverses.

Aerial photography (New South Wales Department of Lands 1963, Kiama series about 1:44 000; New South Wales Department of Main Roads 1962, 1978 series, both about 1:10 000) was used to prepare a vegetation map at a scale of 1:10 000, which has been reduced to a scale of 1:25 000.

Description of plant communities

Ten plant communities were identified (see map in back pocket), ranging from closed-forest (rainforest) to sedgelands. Open-forest, woodland, shrub communities and sedgelands occur on the plateau. The escarpment is characterized by closed-forest and tall open-forest; and the foothills and coastal plain by drier open-forest communities.

Each plant community is described in terms of its structure, habitat and distribution, with the main species present. Variations in structure or species composition related to changes in geology, topography, drainage, aspect and fire are discussed. A species list for the area, and species records for each community, is given in Appendix 1.

The communities described are arranged in sequence from the plateau to the coastal plain.

1. OPEN-FOREST: on Wianamatta Shale on plateau.
2. OPEN-SCRUB: on Wianamatta Shale on plateau.
3. LOW OPEN-FOREST to OPEN-FOREST: on Hawkesbury Sandstone on plateau.
4. OPEN-SCRUB, OPEN-HEATH and LOW SHRUBLAND: on Hawkesbury Sandstone on plateau.
5. SEDGELAND: on plateau.
6. CLOSED-FOREST: mixed warm-temperate/subtropical, warm-temperate, and warm-temperate/cool-temperate rainforests in gullies, sheltered places on escarpment.
7. TALL OPEN-FOREST to OPEN-FOREST: on escarpment.
8. OPEN-FOREST: with dry understorey on escarpment foothills.
9. WOODLAND to OPEN-FOREST: on coastal flats.
10. RIVERINE WOODLAND.

Community 1. OPEN-FOREST: on Wianamatta Shale on plateau

Distribution and habitat: restricted to outcropping Wianamatta Shale and therefore on only a small portion of the study area; generally lying between outcrops of Robertson Basalt (mostly cleared) and Hawkesbury Sandstone (Communities 3, 4 and 5). It occurs more extensively west of the study area.

Structure and floristics: open-forest with trees 20 to 30 m high with a mid-dense foliage cover and a mid-dense to open understorey often dominated by the fern *Culcita dubia.* Main species include the trees *Eucalyptus fastigata, E. radiata* subsp. *radiata, E. obliqua, E. cypellocarpa* and *E. globoidea;* the shrubs *Pultenaea blakelyi, Leucopogon lanceolatus, Persoonia mollis* and *Platysace lanceolata;* climbers such as *Billardiera scandens* and *Hibbertia scandens;* the ferns *Culcita dubia* and *Pteridium esculentum;* and graminoids such as *Lomandra longifolia, Schoenus melanostachys* and *Gahnia* spp.

Comments: variations are largely related to soil type — those downslope from basaltic soils are richer in mafic minerals, while those closer to Hawkesbury Sandstone are influenced by siliceous minerals. Some species overlap into adjacent communities.

The vegetation of the Wianamatta Shale is discussed by Pidgeon (1941) and Phillips (1947). Phillips recognized two associations on the Wingecarribee Tableland: (a) *Eucalyptus radiata* and (b) *E. fastigata — E. viminalis — E. cypellocarpa.* Since Wianamatta Shale occurs in only a small part of the study area, and only two sites were sampled, it is difficult to draw any conclusions about eucalypt associations, or to dispute those recognized by Phillips. However, it is clear that the vegetation on Wianamatta Shale does differ significantly from that on basalt or Hawkesbury Sandstone in this district.

Community 2. OPEN SCRUB: on Wianamatta Shale on plateau

Distribution and habitat: restricted to gently sloping Wianamatta Shale on the fringes of the basalt outcrop at Macquarie Hill.

Structure and floristics: shrubs are dominant, up to 5 m high, with a dense foliage cover; some scattered trees up to 10 m high occur and the ground layer is dominated by graminoids. Main species recorded include the tree *Eucalyptus ovata;* the shrubs *Melaleuca linariifolia, Acacia longifolia, Pultenaea blakelyi* and *Leptospermum flavescens;* ferns such as *Blechnum cartilagineum* and *Pteridium esculentum;* and graminoids such as *Schoenus melanostachys* and *Lomandra longifolia.*

Community 3. LOW OPEN-FOREST to OPEN-FOREST: on Hawkesbury Sandstone on plateau

Distribution and habitat: on the Hawkesbury Sandstone plateau extending inland from the cliff edge; very restricted in Macquarie Pass National Park, but widespread within the M.S.W.D.B. catchment areas to the north.

Structure and floristics: low open-forest to open-forest with trees about 10 m high, a mid-dense foliage cover and a variable understorey of shrubs, ferns and graminoids. The main trees present include *Eucalyptus sieberi, E. smithii, E. piperita* subsp. *urceolaris, E. ligustrina* and *E. dendromorpha* (only at cliff edges). Shrubs are diverse, including *Leucopogon juniperinus, Epacris longifolia, Persoonia mollis, Leptospermum* spp., *Acacia obtusifolia, Banksia spinulosa* and *Pultenaea blakelyi.* The ferns *Culcita dubia, Pteridium esculentum* and *Gleichenia microphylla* occur, while *Sticherus lobatus* and *Blechnum* spp. were noted near creeks. Herbs include *Dampiera stricta* and *Gonocarpus tetragynus,* and the graminoids *Lomandra* spp., *Gahnia clarkei* and *Lepyrodia scariosa* are present.

Comments: considerable variation due to aspect, topographic position (gully, ridge or slope), soil type and proximity to the cliff edge occurs. Among the tree species, *E. sieberi* and *E. dendromorpha* are found close to the cliff edge. *E. smithii* grows in wet gullies, whilst *E. ligustrina* and *E. piperita* subsp. *urceolaris* occur in drier, well-drained places in the catchment areas. Similarly, the understorey varies, with an abundance of ferns along creek lines and scleromorphic species on the drier slopes and ridges.

The sandstone cliffs support a distinct and restricted vegetation, typified by such species as *Dracophyllum secundum, Dendrobium linguiforme, Grammitis billardieri, Eucryphia moorei, Bauera rubioides, Epacris longiflora, Gleichenia* spp. and *Todea barbara.*

Community 4a. OPEN-SCRUB: on Hawkesbury Sandstone on plateau

Distribution and habitat: occurring occasionally on sandy, organic soil in shallow depressions along drainage lines on the Hawkesbury Sandstone.

Structure and floristics: open-scrub with shrubs about 2 m high with mid-dense to dense cover; ground cover dense, dominated by sedges and ferns. The main species present include the shrubs *Melaleuca squarrosa, Leptospermum* spp., *Banksia ericifolia* and *Baeckea linearis;* the fern *Gleichenia microphylla;* and the monocotyledons *Lepyrodia scariosa, Empodisma minus* and *Lepidosperma laterale.*

Community 4b. OPEN-HEATH: on Hawkesbury Sandstone on plateau

Distribution and habitat: one patch only in the study area, in an extensive shallow depression on the plateau, with poorly drained organic sandy soils.

Structure and floristics: open-heath with shrubs to 2 m high, with mid-dense foliage cover; the ground layer is dominated by graminoids. The main species present

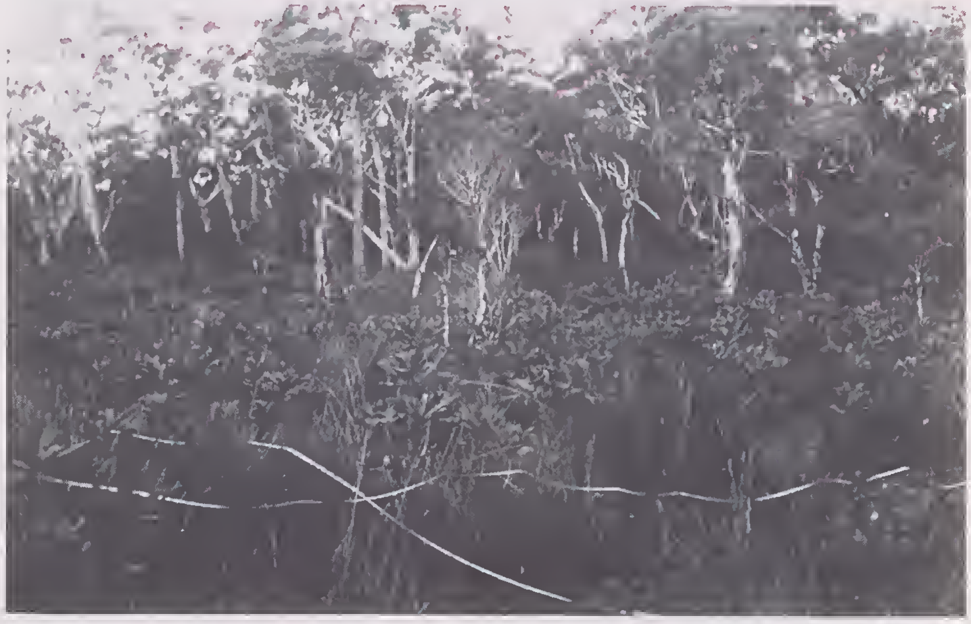

Figure 3. Sedgeland fringed with *Banksia robur* and *Melaleuca linariifolia.* Open-forest with *Eucalyptus piperita* (Community 3) can be seen in the background.

include the shrubs *Banksia ericifolia, Hakea teretifolia, Eucalyptus stricta, Leptospermum attenuatum* and *Banksia paludosa; B. robur, Sprengelia sprengelioides* and the graminoids *Empodisma minus, Sowerbaea juncea* and *Gymnoschoenus sphaerocephalus* occur in moister situations.

Comments: this community occurs on drier sites than Community 4a. The moister sites form a continuum with sedgeland. The mallee, *Eucalyptus stricta,* occurs in somewhat drier, better drained situations.

Community 4c. LOW SHRUBLAND: on Hawkesbury Sandstone on plateau

Distribution and habitat: only one occurrence of this community in the study area; it occupies a very exposed site with shallow, poorly drained soils, adjacent to the cliff edge on Hawkesbury Sandstone.

Structure and floristics: dominated by shrubs about 0.5 m high; taller shrubs and mallee (*Eucalyptus stricta*), 2 to 3 m high, occur as occasional clumps with sparse foliage cover. The main species present are the low shrubs *Petrophile sessilis, Isopogon anemonifolius, Leptospermum squarrosum* var. *rotundifolium, Banksia paludosa* and *Allocasuarina nana;* and as tall shrubs, *Eucalyptus stricta, Leptospermum attenuatum, Acacia obtusifolia, Banksia ericifolia* and *Hakea dactyloides.* Other species recorded include *Patersonia sericea, Lepyrodia scariosa, Leptocarpus tenax, Mitrasacme polymorpha* and *Hemigenia purpurea.*

Community 5. SEDGELAND: on plateau

Distribution and habitat: situated on the Hawkesbury Sandstone plateau in shallow depressions with swampy organic soils. Present also in the M.W.S.D.B. catchment areas to the north and on the plateau further to the south, for example at Barren Grounds Nature Reserve (south-east of Robertson).

Structure and floristics: dominated by graminoids, particularly the families Cyperaceae and Restionaceae; shrubs, when present, are scattered and less than 2 m high (Figure 3). Shrubs recorded include *Banksia robur, Melaleuca linariifolia, Pultenaea linophylla* and *Leptospermum* sp. A. (*L.* sp. aff. *scoparium*). The graminoids *Empodisma minus, Lepyrodia anarthria, Leptocarpus tenax, Lepidosperma laterale* and *Xanthorrhoea resinosa* are common, and herbs such as *Drosera spathulata* and *Goodenia dimorpha* var. *augustifolia* occur with the pteridophyte *Selaginella uliginosa.*

Comment: variation occurs due to differences in drainage and fire history.

Community 6. CLOSED-FOREST: rainforest on escarpment

Recently, Bywater (1978) and Floyd (1981) have classified the types of rainforest on the Illawarra. Bywater (using Webb's (1968) classification) recognized two distinct types:

(a) Mixed notophyll vine–fern forest occurring at altitudes of 150 to 450 m above mean sea level on escarpment benches. These forests receive 1500 to 1600 mm average annual rainfall, with additional moisture from frequent mists, and are on soils derived from Hawkesbury Sandstone, Narrabeen Group talus and Illawarra Coal Measures with relatively low phosphate levels.

(b) Complex notophyll vine forest at lower altitudes (85 to 120 m). The rainfall is much lower, averaging about 1200 mm annually. Soils are derived from latites and soil phosphate levels are markedly higher than on the sedimentary material.

Floyd divides Illawarra rainforests into two types:

a. Predominantly subtropical
  (i) dry/subtropical (=Bywater's complex notophyll vine forest)
  (ii) subtropical

b. Predominantly temperate
  (i) warm-temperate with some subtropical (=Bywater's mixed notophyll vine–fern forest)
  (ii) warm-temperate
  (iii) warm-temperate/cool-temperate.

A mixture of rainforest types occurs at Macquarie Pass. Warm-temperate rainforest is the most widespread type. Subtropical rainforest elements occur with the warm-temperate rainforest only on the fertile soils of the Minnamurra latite bench and in low altitude gully bottoms; much of this has been cleared but remnants still occur. Cool-temperate rainforest elements are found at higher altitudes in the Pass. Although the rainforest at Macquarie Pass has been mapped as one unit, the variations are described below:

a. *Mixed warm-temperate/subtropical rainforest*

Distribution and habitat: subtropical rainforest elements occur on soils derived from latite, on benches on the escarpment (themselves formed from latite bands within the Illawarra Coal Measures) and in low altitude gully bottoms. This vegetation type is uncommon now because of extensive clearance of the benches, for example at "Clover Hill".

Structure and floristics: closed-forest with 10 to 30 m high trees and occasional emergents; foliage cover dense. The open understorey consists of ferns, vines, scattered shrubs, mosses and lichens. The main trees present include *Doryphora sassafras, Ceratopetalum apetalum, Livistona australis, Pennantia cunninghamii, Cryptocarya glaucescens* and *Toona australis. Citriobatus pauciflorus* and *Hymenanthera dentata* occur as shrubs, with the tree-ferns *Cyathea australis* and *C. leichhartiana.* The vines *Palmeria scandens, Cissus hypoglauca. Parsonsia straminea, Marsdenia* spp. and the climbing fern *Arthropteris tenella* are present. *Lastreopsis microsora* and *Doodia aspera* dominate the ground layer.

b. *Warm-temperate rainforest*

Distribution and habitat: found in gullies, along creek lines and in other sheltered areas protected by the escarpment cliffs; predominantly on sandstone talus slopes or on sandstones of the Illawarra Coal Measures. The soils are generally of texture-contrast type.

Structure and floristics: structure is similar to the subtropical rainforest described above, but the trees are often shorter. Main tree species are *Ceratopetalum apetalum, Doryphora sassafras, Cryptocarya glaucescens. Acmena smithii, Polyosma cunninghamii. Abarema sapindoides* and *Dendrocnide excelsa.* Shrubs such as *Tasmannia insipida, Eupomatia laurina* and *Clerodendrum tomentosum,* and vines such as *Malaisia scandens* and *Marsdenia rostrata* were recorded. The ferns *Dicksonia antarctica, Cyathea australis* and *Lastreopsis acuminata* are present in the understorey with species such as *Gymnostachys anceps* and *Australina pusilla.*

c. *Mixed warm-temperate/cool-temperate rainforest*

Distribution and habitat: cool-temperate rainforest elements are found just below the cliff-line at Macquarie Pass. This type of vegetation was once much more extensive on the basaltic Robertson Plateau (Phillips, 1947), but now only small patches remain; the largest of these is Robertson Nature Reserve (4.5 ha at 750 m altitude).

Structure and floristics: rainforest with trees 10 to 20 m high but sometimes dwarfed in more exposed situations. Foliage cover is dense. Many ferns and a number of vines are present, but there are no epiphytes. Species recorded include the trees *Doryphora sassafras, Quintinia sieberi, Ceratopetalum apetalum, Rapanea howittiana, Polyosma cunninghamii* and *Eucryphia moorei* (the last at the top of Macquarie Pass, but not at Robertson Nature Reserve); the shrubs *Hymenanthera dentata, Tasmannia insipida, Citriobatus pauciflorus* and *Notelaea venosa;* and the vines *Eustrephus latifolius, Smilax australis* and *Marsdenia rostrata.* Ferns such as *Dicksonia antarctica, Lastreopsis microsora* and *Pyrrosia rupestris,* and the herbs *Gymnostachys anceps* and *Urtica incisa* are also present.

Community 7. TALL OPEN-FOREST to OPEN-FOREST: on escarpment

Distribution and habitat: community 7 occurs in a more-or-less continuous band below the cliff-line on the upper slopes of the Illawarra escarpment (about 550 m altitude), and on ridges and in sheltered valleys down to about 250 m and 80 m altitude respectively (Figure 4). It is usually in association with closed-forest, which occupies the more sheltered positions. Soils vary with parent material, but generally tend to be duplex in structure. Floristic associations are described below; these are associated with different geological substrates.

a. *Sandstone talus*

At lower altitudes *Eucalyptus muelleriana* and *Syncarpia glomulifera* are dominant. *Eucalyptus smithii* and *E. fastigata* become increasingly important above 150 m altitude and are the major tree species on the upper slopes of the escarpment. Other tall tree species present are *E. botryoides–saligna* intergrade, *E. quadrangulata* and *E. sieberi.* Other species occurring throughout include the small trees *Acacia binervata* and *Cryptocarya glaucescens;* the shrubs *Rhodamnia rubescens, Acmena smithii, Persoonia linearis, Clerodendrum tomentosum, Synoum glandulosum, Elaeocarpus reticulatus* and *Zieria smithii;* the climbers *Morinda jasminoides, Marsdenia rostrata, Tylophora barbata, Stephania japonica* and *Smilax* spp.; and the ferns *Culcita dubia, Doodia aspera* and *Blechnum cartilagineum.*

b. *Narrabeen Group Sediments (primarily on Johnsons Ridge)*

(i) Coal Cliff Sandstone

The main trees include *Eucalyptus muelleriana, E. smithii, E. quadrangulata* and *Allocasuarina torulosa.* The understorey is dominated by shrubs such as *Oxylobium ilicifolium.*

(ii) Wombarra Claystone

The tree species recorded are the same as for the Coal Cliff Sandstone. *Goodenia ovata* dominates the understorey; other species present include *Pimelea ligustrina, Olearia argophylla, Senecio velleioides, Cynoglossum australe, Logania albiflora, Cassinia aureonitens, Acacia binervata* and *Tylophora barbata.*

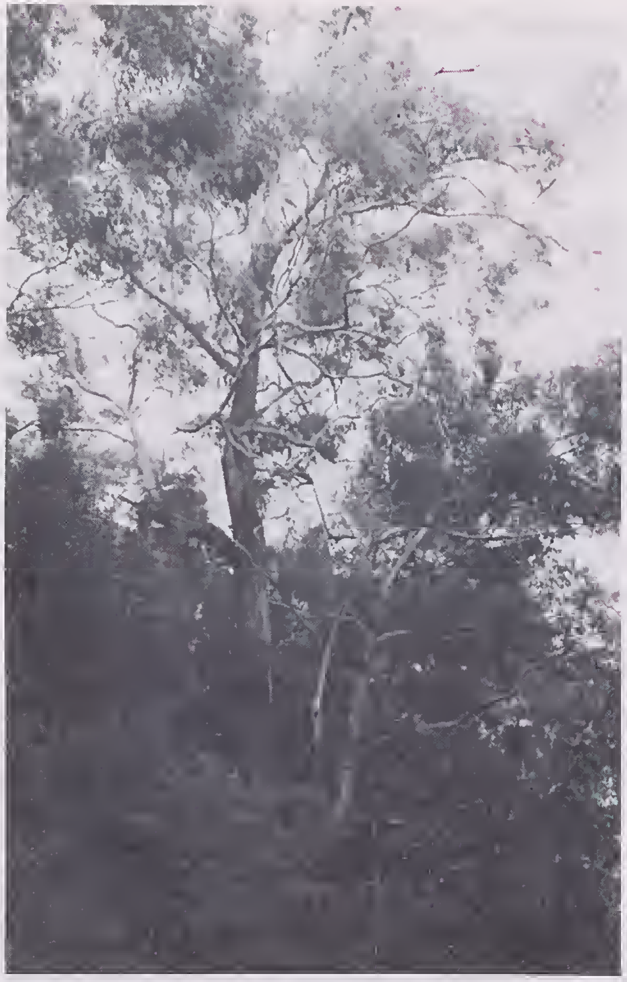

Figure 4. *Eucalyptus smithii* on talus on the escarpment in Community 7.

(iii) Colo Vale Sandstone

The main tree species include *Eucalyptus sieberi, E. smithii, E. quadrangulata, E. muelleriana* and *E. piperita* subsp. *urceolaris.* The understorey near the cliff-line is moist, including species such as *Backhousia myrtifolia, Acacia binervata, Clerodendrum tomentosum, Rapanea variabilis, Pittosporum undulatum, Elaeocarpus reticulatus, Synoum glandulosum* and *Tristaniopsis collina.* Understorey species on a dry knoll on Johnsons Ridge include *Persoonia pinifolia, Oxylobium ilicifolium, Lomandra longifolia, Cyathochaeta diandra, Amperea xiphoclada, Comesperma ericinum, Smilax glyciphylla* and *Pteridium esculentum.*

Comments: logging and clearing in the past have had significant effects on this community. A large part of the forest, on the talus particularly, shows signs of disturbance. Evidence of regeneration is provided by dense growth of saplings, especially *Syncarpia glomulifera* and *Doryphora sassafras,* resulting in a variety of more-or-less even-age stands of some tree species. The understorey does not appear to vary greatly except in places of recent disturbance.

Community 8. OPEN-FOREST: with dry understorey on escarpment foothills

Distribution and habitat: occurring on the foothills of the escarpment and sometimes extending onto the coastal plain, where rainfall is lower than close to the escarpment; on various geological formations, usually Permian volcanic sandstones and latites. Much of this community has been disturbed or cleared for grazing.

Structure and floristics: open-forest of trees, 10 to 20 m high with mid-dense foliage cover and a dry understorey of shrubs, herbs and monocotyledons. The main trees present are *Eucalyptus tereticornis* and *E. globoidea,* with *E. botryoides–saligna* intergrade along the moister gullies. The shrubs *Breynia oblongifolia, Acacia* spp. and *Indigofera australis* are present as well as the climbers *Kennedia rubicunda* and *Geitonoplesium cymosum.*

Community 9. WOODLAND to OPEN-FOREST: on coastal flats

Distribution and habitat: this community occupies Permian sediments (Budgong Sandstone and Berry Siltstone) on the undulating coastal plain. Formerly it would have been widespread north of Albion Park, but now only remnants occur.

Structure and floristics: woodland to open-forest with trees 10 to 30 m tall, with foliage cover ranging from sparse to mid-dense. The understorey is generally open and dominated by grasses. The main tree species on the drier rises are *Eucalyptus longifolia, E. eugenioides, Angophora floribunda* and *Melaleuca decora,* whilst in depressions and near creeks *E. amplifolia, Melaleuca styphelioides* and *Casuarina glauca* occur. Scattered shrubs such as *Acacia mearnsii, A. falcata, Dodonaea viscosa, Olearia viscidula, Daviesia ulicifolia* and *Hakea dactyloides* are recorded, with the monocotyledons *Dichelachne micrantha, Entolasia stricta, Imperata cylindrica, Dianella caerulea* and *Laxmannia gracilis.*

Comments: the largest remaining area of this community in the region is near Yallah (north-east of Albion Park). It is divided in two by transmission lines, and has also been used for grazing. This is the only known locality of the orchid *Pterostylis serifolia.* Most remnants of this community will have been grazed, burnt and selectively logged, so the understorey species composition may have been considerably altered.

Community 10. RIVERINE WOODLAND

Distribution and habitat: occurring on the banks of the Macquarie Rivulet on alluvial soils.

Structure and floristics: woodland with trees 10 to 25 m high with open foliage cover. The main species present are *Casuarina cunninghamiana* and *Erythrina × sykesii* (Coral Tree), an introduced species.

Comments: this community is generally very disturbed in the study area. Weeds from adjacent farming land are prevalent. Fuller (1980), in a study of the northern Illawarra, noted the presence of *Casuarina cunninghamiana* on Marshall Mount Creek; other creeks further north on the coastal plain, where rainfall is higher, apparently had rainforest species on their banks, while those further south, for example Minnamurra River, have *Casuarina cunninghamiana. Casuarina glauca* occurs on stream banks closer to the coast.

DISCUSSION

There have been a number of studies of the Illawarra vegetation, mostly of a general nature. Hamilton (1914) divided the vegetation into four main types:

- beach and sand dune flora
- open forest on the coastal plain and foothills of the escarpment
- subtropical jungle in gullies and seaward slopes of the mountain range
- sandstone association on the top of the range.

This division agrees well with the broad conclusions of this study, although the beach and sand dune flora do not occur in the study area.

Davis (1936, 1941a, b) studied the Bulli district (where the Illawarra escarpment curves eastward to the sea) and described the vegetation of the plateau, the slopes and the coastal plain in considerable detail. He found that, on the slopes of the escarpment in drier locations where "brush" (rainforest) did not occur, *Eucalyptus pilularis* was dominant, commonly associated with *E. paniculata* and *Syncarpia glomulifera.* Although *Syncarpia* is common at Macquarie Pass, neither of the eucalypt species occurs there. In similar positions at Macquarie Pass, *E. muelleriana, E. fastigata* and *E. smithii* are the dominants. The understorey appears to be similar in both places. The differences between the two areas are most likely due to the warmer temperatures, proximity to the sea and lower annual rainfall at Bulli (1400 to 1500 mm). Davis found "brush" in sheltered positions immediately below the scarp, in gullies on the lower slopes, and on soils derived from Chocolate Shale. Similarly, in our study, rainforest on the plateau on Narrabeen and Hawkesbury Sandstone was found to occur in very sheltered positions and was floristically poorer than that on the coast.

Rainforests on the Illawarra

Many people associate the Illawarra region with rainforest. Indeed, the scenic attraction of Macquarie Pass is largely based on the rainforest and moist eucalypt forest. This had led to an exaggeration of the importance of rainforests in the region and some debate over the years concerning its original extent. Early descriptions of the vegetation of the Illawarra frequently refer to "brush", which is often interpreted as referring to rainforest, although it seems likely that this word was used for any moist dense forest. For example, Maiden (1914) discusses "brush" in the County of Cumberland and lists *Syncarpia glomulifera* (Turpentine) amongst the common canopy species. *Syncarpia glomulifera* is not a species typical of rainforest, although it is often an emergent or associated with a moist understorey dominated by mesophyllous (or rainforest-type) shrubs ("wet sclerophyll forest"). At Macquarie Pass, *Syncarpia* and *Eucalyptus* spp. are the dominant canopy species of the tall open-forest.

Pidgeon (1937) gives a brief account of the Illawarra rainforest, saying that it is a remnant of forest that "once covered the slopes and valleys of the Illawarra from Bulli to Berry". She based this on the widespread distribution of *Livistona australis.* Davis (1936) had already singled out this species as being the most abundant and characteristic of the "brush" at Bulli. This species is frequently found in rainforest, but may also occur in other forest types, for example open eucalypt forest near Otford, north of Bulli, or swamp forests. Hence the remnant individuals on the Illawarra do not necessarily indicate the previous existence of rainforest. *Livistona australis* is extremely-fire-resistant (A. Floyd, pers. comm.) and this may account for its common survival in cleared areas; or it may have been retained for its ornamental value.

It seems, then, that the theories of extensive rainforest on the Illawarra (such as in Pidgeon, 1937; Baur, 1957; Strom, 1977) at the time of European settlement are probably overestimations. However, it is very likely that there were extensive forests with moist understories ("wet sclerophyll forests") in which *Livistonia australis* was common. As Floyd (1981) states, "Rainforest in the Illawarra was originally restricted to areas of deep moderately fertile soil with high and reliable rainfall. Protection from wildfire and desiccating and cold winds was also required".

Clearing of rainforest has been extensive on the coastal lowlands, the Robertson Plateau and the benches of the escarpment. Few stands of Floyd's lowland "dry/ subtropical" rainforest remain on the Illawarra. The best known example is at Whispering Gallery between Albion Park and Jamberoo. It is in a steep gully on latite and both subtropical and dry rainforest species occur; it is on freehold land and so not adequately protected. Subtropical rainforest is well represented at Minnamurra Falls. Some small pockets can be found on the escarpment, for example on Macquarie Rivulet near Clover Falls. Warm-temperate/subtropical rainforest is well represented at Macquarie Pass. Elements of warm-temperate/cool-temperate rainforest are found at the highest altitudes at Macquarie Pass just below the cliffs. However, on the Robertson Plateau where it was once extensive, only Robertson Nature Reserve and a few smaller refuges remain. (Often these small refuges are dominated by *Acacia melanoxylon,* which may be regrowth after disturbance.)

Macquarie Pass National Park contains 190 hectares of rainforest (National Parks & Wildlife Service of New South Wales, 1979); it is therefore regionally important in rainforest conservation, particularly of warm-temperate rainforest.

Disturbance and regeneration

Most of Macquarie Pass was divided into 40 and 60 acre (16 and 24 ha) portions between 1856 and 1906. Investigation of the surveyors' site descriptions gives some information on the dominant tree species in the area, but very little indication on the density of species (Table 1). The area was generally described as "heavily timbered

TABLE 1

Species mentioned in surveys at Macquarie Pass between 1856 and 1888

Surveyors' nomenclature*	Probable botanical name in this area
Ash	*Eucalyptus ?smithii*
Blackbutt	*Eucalyptus pilularis*† (possibly *E. smithii*)
Blackwattle	*Acacia mearnsii*†, *Callicoma serratifolia* or *Acacia binervata*
Box	*Eucalyptus* spp. (possibly *E. quadrangulata*)
Brushwood(s)	Mesophyllous tree and shrub species
Cabbage Tree	*Livistona australis*
Corkwood	*Duboisia myoporoides* or *Endiandra sieberi*
Featherwood	*Polyosma cunninghamii*
Leatherjacket	*Ceratopetalum apetalum*
Lilly Pilly	*Acmena smithii*
Messmate	*Eucalyptus fastigata* or *E. obliqua*†
Sycamore	Uncertain, possibly *Cryptocarya* sp.
Tea Tree	*Leptospermum* spp. or *Melaleuca* spp.
Turpentine	*Syncarpia glomulifera*
Wattle	*Acacia ?binervata* or synonym for blackwattle

* On portion plan, New South Wales Department of Lands

† Species does not occur on the escarpment at Macquarie Pass

turpentine, stringybark, wattle etc". The dominant canopy species appear to be almost identical with those present in the forest today, and the understorey in the eucalypt forest was moist and mesophyllous — for example, "Chiefly messmate [probably *Eucalyptus fastigata*] and brushwood". Only two portion descriptions indicate a rainforest community — one of these is located in an area just below the escarpment and is still warm-temperate rainforest today; the other, at "Clover Hill", is on a latite band that supported subtropical rainforest and is now cleared.

With the decline in the dairy industry and the reduction in population density at the end of the last century, some cleared areas were neglected and regeneration of native forests began. The regeneration has taken place during this century, and probably mainly in the last 40 to 50 years (Bob Dalhunty, pers. comm.). The similarity of these forests to the original vegetation is uncertain in terms of structure and species importance. It does seem, however, that most of the original canopy species still occur.

Evidence for disturbance in tall open-forest includes old (logging) tracks, sites of huts, frequent sawn stumps, piles of rocks, dense growth of young trees in virtually single-age stands (especially *Syncarpia glomulifera* and *Cryptocarya* spp.) (Table 2), very few trees with basal diameters similar to or greater than those of the remaining stumps, and a very simple understorey (Figure 5). Within the closed-forest, old logging tracks, stumps of trees such as *Toona australis*, few large old trees, the coppicing of several species, the frequent occurrence of common colonizing species such as *Acacia binervata*, *Euodia micrococca*, *Dendrocnide excelsa* and *Polyscias murrayi*, often as quite large trees, and substantial areas of forest with many vines (indicating an open canopy at one time) (A. Floyd, pers. comm.) all indicate disturbance over a considerable time.

Hamilton (1914) mentions several introduced species common on the Illawarra at that time. "Introduced plants do not get much hold in virgin brush, but wherever it is disturbed, there are certain noxious plants which make headway. The worst of these are — [the exotic] *Phytolacca octandra*, *Lantana camara* and *Rubus fructicosus*." He mentions a few other species to be common in the brush near settlements — the peach (**Prunus persica*), rough-skinned lemon (**Citrus jambiri*), Cape gooseberry (**Physalis peruviana*) and passionfruit (**Passiflora edulis*).

TABLE 2

Size distributions of selected tree species

Species	Forest type*	No. of individuals with dbh		Total no. individuals
		< 10 cm	10–15 cm	
Cryptocarya glaucescens	TOF	9	2	11
	TOF	19	0	19
	TOF	27	9	37
	TOF	13	8	23
Doryphora sassafras	CF	10	5	25
	CF	9	13	29
Syncarpia glomulifera	TOF	31	12	49
	TOF	20	8	34
Ceratopetalum apetalum	CF	13	10	23

* TOF: Tall open-forest; CF: Closed-forest

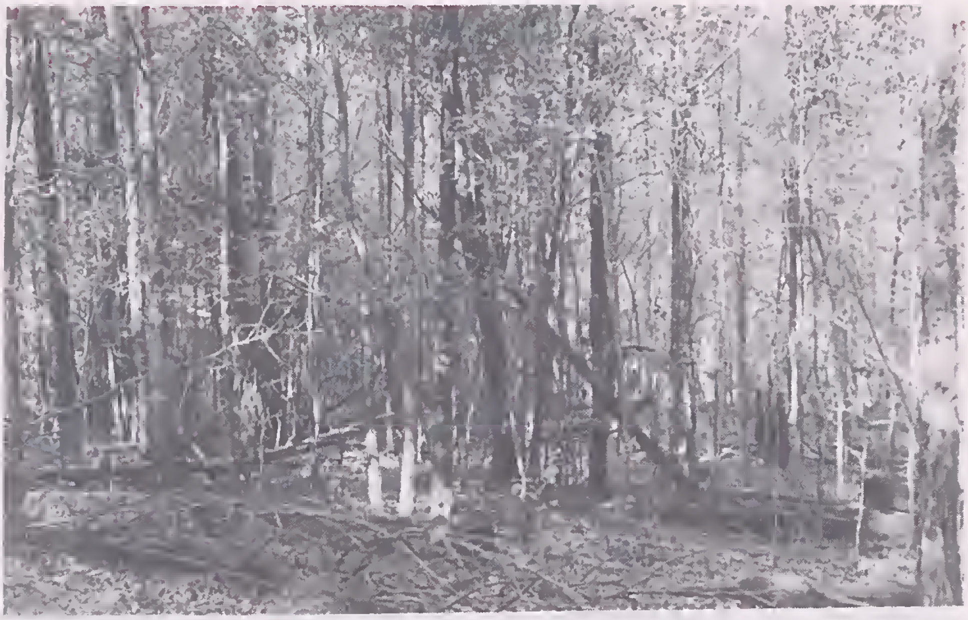

Figure 5. Evidence for disturbance in tall open-forest — sawn logs and stumps, dense growth of young trees (*Eucalyptus smithii*, *E. fastigata* and *Syncarpia glomulifera*), very few large trees and a very simple understorey.

At Macquarie Pass, weeds are restricted mainly to sites of recent disturbance, and associated with edges of clearings and roadsides. The main weed infestations are at the lower altitudes. Here, the most abundant weed species are the exotics **Lantana camara*, **Rubus* spp., **Pennisetum clandestinum*, **Sida rhombifolia*, **Tradescantia albiflora* and **Senecio mikanioides*. *Lantana* is the biggest problem, growing more densely and extensively at the edges of clearings than along the roadsides; it appears to grow only at lower altitudes, generally not above about 300 m. Large areas dominated by *Lantana* are shown on the map (inside back cover). Higher on the escarpment slopes at Macquarie Pass, weed infestations are not as extensive. Other disturbed areas, mainly at roadsides, are colonized by native species and some introduced weed species. The most common colonizing species are *Urtica incisa*, **Ageratina adenophora*, **A. riparia*, *Senecio liniarifolia*, *Lastreopsis decomposita* and **Rubus* spp. **Ligustrum sinense* is the most common weed in the warm-temperate/cool-temperate rainforest at Robertson Nature Reserve.

CONCLUSIONS

The vegetation pattern seen in the Macquarie Pass area represents a broad west-to-east transect through the plant communities from the plateau to the coastal plain on the Illawarra. The diversity of the plant communities strongly reflects patterns in geology, climate and topography.

The settlement history of the area has had lasting effects on the vegetation of the coastal plain and escarpment. The more arable areas have been cleared, but regeneration of cleared and logged sites has occurred, especially on the escarpment. Evidence of past disturbance can be found in these forests.

Only remnants of some communities can be found on the coastal plain and they are not protected. The vegetation conserved in Macquarie Pass National Park is representative of the escarpment slopes (moist eucalypt-dominated open-forest) and of rainforest.

ACKNOWLEDGMENTS

We wish to thank R.G. Coveny and the staff of the National Herbarium of New South Wales for help with the identification of plant specimens; and D.H. Benson, J.M. Powell and M.D. Fox for encouragement, comment and advice during the preparation of this manuscript. We also thank Bob Dalhunty and Alex Floyd for useful and enjoyable discussions.

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APPENDIX 1

Species list for Macquarie Pass district

This list is arranged alphabetically in families and genera within the following divisions: Pteridophytes, Angiosperms — Dicotyledons, and Angiosperms — Monocotyledons. Exotic species are marked with an asterisk. Names are those currently recognized at the National Herbarium of New South Wales (Jacobs & Pickard, 1981, except where subsequent revisions or nomenclatural changes have occurred). Pryor & Johnson (1971) codes are used with eucalypt names.

List of plant community names and numbers

1. OPEN-FOREST: on Wianamatta Shale on plateau.
2. OPEN-SCRUB: on Wianamatta Shale on plateau.
3. LOW OPEN-FOREST to OPEN-FOREST: on Hawkesbury Sandstone on plateau.
4. OPEN-SCRUB, OPEN-HEATH and LOW SHRUBLAND: on Hawkesbury Sandstone on plateau.
5. SEDGELAND: on plateau.
6. CLOSED-FOREST: mixed warm-temperate/subtropical, warm-temperate, and warm-temperate/cool-temperate rainforests in gullies, sheltered places on escarpment.
7. TALL OPEN-FOREST to OPEN-FOREST: on escarpment.
8. OPEN-FOREST: with dry understorey on escarpment foothills.
9. WOODLAND to OPEN-FOREST: on coastal flats.
10. RIVERINE WOODLAND.

Species	Community number									
PTERIDOPHYTES										
ADIANTACEAE										
Adiantum formosum						6	7		9	
A. hispidulum						6				
Cheilanthes tenuifolia						6	7		9	
Pellaea falcata						6			9	
ASPIDIACEAE										
Lastreopsis acuminata						6				
L. decomposita									9	
L. microsora						6				
ASPLENIACEAE										
Asplenium australasicum						6				
A. flabellifolium						6	7			
BLECHNACEAE										
Blechnum ambiguum			3							
B. cartilagineum	1	2				6	7			
B. nudum	1		3							
B. patersonii			3			6				
B. wattsii			3							
Doodia aspera						6	7		9	
CYATHEACEAE										
Cyathea australis	1		3			6	7			
C. leichhardtiana						6				
Dicksonia antarctica						6				
Culcita dubia	1		3				7		9	
DAVALLIACEAE										
Arthropteris tenella						6				
Davallia pyxidata						6				
DENNSTAEDTIACEAE										
Histiopteris incisa			3							
Hypolepis muelleri						6				
H. punctata						6				
Pteridium esculentum	1	2	3				7		9	
GLEICHENIACEAE										
Gleichenia dicarpa			3	4						
G. microphylla			3	4						
Sticherus lobatus	1		3				7			
GRAMMITIDACEAE										
Grammitis billardieri			3							
HYMENOPHYLLACEAE										
Hymenophyllum cupressiforme						6				
LINDSAEACEAE										
Lindsaea linearis			3	4						
L. microphylla							7			
LYCOPODIACEAE										
Lycopodium sp.			3							
OSMUNDACEAE										
Todea barbara			3			6				
POLYPODIACEAE										
Microsorium scandens						6				
Pyrrosia rupestris			3			6				
PTERIDACEAE										
Pteris umbrosa						6				
SELAGINELLACEAE										
Selaginella uliginosa							7			
SCHIZAEACEAE										
Schizaea bifida			3							
SINOPTERIDACEAE										
Pellaea falcata var. *falcata*						6				
ANGIOSPERMS — DICOTYLEDONS										
ACANTHACEAE										
Pseuderanthemum variable							7			10
ANACARDIACEAE										
Euroschinus falcata			3							

APIACEAE										
Actinotus minor				4						
Hydrocotyle sp.			3		5	6	7			
Platysace ericoides	1									
P. lanceolata	1		3		5					
P. linearifolia			3							
Xanthosia pilosa			3							
X. tridentata			3							
APOCYNACEAE										
Parsonsia brownii	1		3			6	7			
P. straminea						6	7		9	
ARALIACEAE										
Astrotricha latifolia							7			
Polyscias elegans							7			
P. murrayi						6	7			
ASCLEPIADACEAE										
Marsdenia flavescens						6				
M. rostrata	1		3			6	7			
Tylophora barbata	1		3			6	7			
ASTERACEAE										
**Ageratina adenophora*							7			
**A. riparia*							7			
**Bidens pilosa*							7			
Cassinia aureonitens							7		9	
C. trinerva						6	7	8		
C. sp.	1				5					
**Cirsium vulgare*							7			
**Conyza* spp.							7			
Cotula australis							7			
Gnaphalium sp.	1						7			
Helichrysum ?argophyllum						6	7			
H. diosmifolium							7			
H. elatum					5	6				
H. rutidolepis							7			
H. viscosum	1						7			
**Hypochoeris radicata*							7		9	
?Lagenifera stipitata						6	7		9	
Olearia argophylla					5	6	7			
O. viscidula							7		9	
Senecio linearifolius	1				5	6	7			
**S. mikanioides*						6	7	8		
S. velleioides							7			
**Sonchus oleraceus*							7			
BAUERACEAE										
Bauera rubioides	1	2	3	4						
BIGNONIACEAE										
Pandorea pandorana						6	7			
BORAGINACEAE										
Cynoglossum australe							7			
C. latifolium						6				
**Echium lycopsis*							7			
CAMPANULACEAE										
Wahlenbergia sp.									9	
CARYOPHYLLACEAE										
**Silene gallica*							7		9	
Stellaria flaccida			3			6	7			
CASSYTHACEAE										
Cassytha paniculata			3							
C. pubescens			3							
CASUARINACEAE										
Allocasuarina distyla			3							
A. littoralis			3		5					
A. nana		2		4						
A. torulosa						6	7		9	
Casuarina cunninghamiana										10
C. glauca									9	
CELASTRACEAE										
Elaeodendron australe						6	7			

CHENOPODIACEAE									
Einadia hastata							7		
E. nutans			3				7		
CONVOLVULACEAE									
Dichondra repens							7	8	
CUNONIACEAE									
Aphanopetalum resinosum						6			
Ceratopetalum apetalum						6	7		
Schizomeria ovata						6	7		
CRASSULACEAE									
Crassula sieberiana						6			
DILLENIACEAE									
Hibbertia dentata							7	8	
H. empetrifolia	1								
H. scandens	1					6	7		
H. stricta				4					
DROSERACEAE									
Drosera auriculata			3						
D. binata					5				
D. peltata			3						
D. spathulata				4	5				
EBENACEAE									
Diospyros australis						6	7		
EHRETIACEAE									
Ehretia acuminata							7		
ELAEOCARPACEAE									
Elaeocarpus reticulatus	1	2	3				7		
ELATINACEAE									
Elatine gratioloides			3						
EPACRIDACEAE									
Brachyloma daphnoides				4					
Dracophyllum secundum			3						
Epacris coriacea			3						
E. longiflora			3						
E. microphylla				4					
E. obtusifolia			3	4	5				
Leucopogon juniperinus			3				7		
L. lanceolatus	1		3	4		6	7		
Monotoca ledifolia				4					
Sprengelia incarnata				4	5				
S. sprengelioides				4					
Trochocarpa laurina						6			
ESCALLONIACEAE									
Polyosma cunninghamii						6			
Quintinia sieberi			3			6			
EUCRYPHIACEAE									
Eucryphia moorei			3			6			
EUPHORBIACEAE									
Amperea xiphoclada			3				7		
Beyeria lasiocarpa							7		
Breynia oblongifolia						6	7	8	9
Claoxylon australe						6	7		
Glochidion ferdinandi								8	
Omalanthus populifolius							7		
Phyllanthus gasstroemii							7		
Poranthera corymbosa			3						
P. microphylla			3				7		
EUPOMATIACEAE									
Eupomatia laurina						6	7		
FABACEAE									
Abarema sapindoides						6			
Acacia binervata						6	7		9
A. falcata									9
A. implexa								8	
A. longifolia	1	2							
A. maidenii	1						7		
A. mearnsii									9
A. melanoxylon						6	7		

A. myrtifolia			3							
A. obtusifolia	1		3	4						
A. stricta									9	
A. suaveolens			3	4						
A. terminalis			3							
A. ulicifolia			3	4						
Aotus ericoides			3							
Bossiaea heterophylla			3						9	
Daviesia genistifolia									9	
D. ulicifolia									9	
Desmodium rhytidophyllum							7			
D. varians							7			
Dillwynia floribunda			3	4	5		7			
**Erythrina* × *sykesii*										10
Glycine clandestina							7		9	
Gompholobium glabratum			3	4						
Hardenbergia violacea							7		9	
Indigophora australis							7	8		
Kennedia rubicunda	1						7	8	9	
Mirbelia rubiifolia				4						
Oxylobium ilicifolium							7			
Pultenaea blakelyi	1	2	3		5		7			
P. daphnoides			3		5				9	
P. ?divaricata					5					
P. linophylla			3		5				9	
P. paludosa					5					
P. ?retusa					5					
P. villosa									9	
Sphaerolobium vimineum				4						
**Trifolium repens*							7			
GENTIANACEAE										
Centaurium spicatum							7			
GERANIACEAE										
Geranium ?homeanum									9	
G. sp.			3			6				
GESNERIACEAE										
Fieldia australis			3			6				
GOODENIACEAE										
Dampiera purpurea	1									
D. stricta			3	4	5					
Goodenia ?dimorpha var. *angustifolia*					5					
G. hederacea					5					
G. ovata	1	2	3			6	7		9	
G. stelligera				4						
HALORAGACEAE										
Gonocarpus tetragynus	1									
G. teucrioides	1	2	3	4			7			
ICACINACEAE										
Citronella moorei						6				
Pennantia cunninghamii						6				
LAMIACEAE										
Hemigenia purpurea				4						
Plectranthus parviflorus							7			
Prostanthera lasianthos							7			
Prunella vulgaris							7			
Teucrium corymbosum							7			
LAURACEAE										
Cryptocarya glaucescens						6	7			
C. microneura							7			
LOBELIACEAE										
Pratia purpurascens	1						7			
LOGANIACEAE										
Logania albiflora							7		9	
Mitrasacme polymorpha				4	5					
LORANTHACEAE										
Amyema gaudichaudii									9	
MALVACEAE										
Hibiscus heterophyllus						6				
**Modiola caroliniana*							7			
**Sida rhombifolia*							7			

MELIACEAE									
Melia azedarach var. *australasica*							7		
Synoum glandulosum	1					6	7		
Toona australis						6			
MENISPERMACEAE									
Legnephora moorei						6			
Sarcopetalum harveyanum						6	7		
Stephania japonica var. *discolor*						6	7		
MONIMIACEAE									
Doryphora sassafras						6	7		
Hedycarya angustifolia						6	7		
Palmeria scandens			3			6	7		
MORACEAE									
Ficus coronata						6			
F. obliqua						6			
Maclura cochinchinensis						6			
Malaisia scandens						6			
Streblus brunonianus						6			
MYOPORACEAE									
Myoporum acuminatum							7		
MYRSINACEAE									
Rapanea howittiana						6	7		
R. variabilis						6	7		
MYRTACEAE									
Acmena smithii						6	7		
Angophora floribunda									9
Backhousia myrtifolia							7		
Baeckea diosmifolia				4					
B. linearis				4					
Callistemon citrinus				4					
Eucalyptus amplifolia SNEEA									9
E. bosistoana SUNCA									9
E. botryoides-saligna SECAD-SECAC (intergrading population)							7	8	
E. cypellocarpa SPIFE	1								
E. dendromorpha MAKID			3						
E. eugenioides MAHEA								8	9
E. fastigata MAKCB	1		3				7		
E. globoidea MAHEF	1							8	
E. gummifera CAFUF			3						
E. ligustrina MAHEQ			3						
E. longifolia SECGA									9
E. mannifera SPECH			3						
E. muelleriana MAHAA							7		
E. obliqua MAKAA	1								
E. ovata SPEAB		2							
E. piperita ssp. *urceolaris* MATHAC			3						
E. quadrangulata SPIHA						6	7		
E. radiata ssp. *radiata* MATELA	1								
S. sieberi MAKID	1		3						
E. smithii SPIKE			3				7		
E. stricta MAKIG				4					
E. tereticornis SNEEB				4					
Kunzea ?cambagei				4					
Leptospermum attenuatum			3	4	5		7		
L. flavescens (large form)		2	3						
L. juniperinum sens. str.				4					
L. scoparium var. *rotundifolium*			3	4					
L. squarrosum		2	3	4	5				
L. sp. *A*		2	3		5				
Melaleuca decora									9
M. linariifolia		2			5				
M. squarrosa		2		4					
M. styphelioides									9
Rhodamnia rubescens							7		9
Syncarpia glomulifera							7		
Tristaniopsis laurina						6	7		
T. collina	1		3				7		
OLEACEAE									
**Ligustrum lucidum*						6			
**L. sinense*						6			
Notelaea longifolia						6	7		
N. venosa						6	7		

PASSIFLORACEAE										
Passiflora cinnabarina							7			
P. herbertiana							7			
**P. subpeltata*							7			
PHYTOLACCACEAE										
**Phytolacca octandra*							7			
PITTOSPORACEAE										
Billardiera scandens	1		3				7			
Bursaria spinosa				4		6	7	8		
Citriobatus pauciflorus						6	7			
Pittosporum revolutum							7	8		
P. undulatum			3			6	7			
PLANTAGINACEAE										
**Plantago lanceolata*							7			
POLYGALACEAE										
Comesperma ericinum				4			7			
C. volubile			3							
POLYGONACEAE										
**Acetosa sagittata*							7			
PROTEACEAE										
Banksia aspleniifolia					5					
B. ericifolia			3	4	5					
B. paludosa				4						
B. robur				4	5					
B. serrata			3	4						
B. spinulosa			3							
Conospermum sp.			3							
Grevillea oleoides			3						9	
G. parviflora				4						
G. sericea					5					
Hakea dactyloides			3	4			7		9	
H. salicifolia		2				6				
H. teretifolia			3	4						
Isopogon anemonifolius			3	4						
I. anethifolius			3	4						
Lambertia formosa			3	4						
Lomatia silaifolia			3							
Persoonia linearis	1					6	7			
P. levis	1		3							
P. mollis	1		3	4			7			
P. pinifolia							7			
Petrophile pedunculata			3							
P. sessilis			3	4						
Stenocarpus salignus						6	7			
Telopea speciosissima	1									
RANUNCULACEAE										
Clematis aristata	1					6	7			10
RHAMNACEAE										
Alphitonia excelsa						6			9	
Pomaderris aspera							7			
ROSACEAE										
Acaena sp.							7	8		
**Prunus persica*							7			
Rubus hillii						6	7			
R. moorei			3			6	7			
R. rosifolius						6				
**R. vulgaris*							7			
RUBIACEAE										
Asperula conferta									9	
Coprosma quadrifida						6				
Morinda jasminoides						6	7			
Opercularia varia							7			
Psychotria loniceroides							7			
RUTACEAE										
Acronychia oblongifolia								8		
Boronia floribunda			3							
B. polygalifolia									9	
Euodia micrococca							7	8	9	
Phebalium squameum							7			
Zieria pilosa			3							
Z. smithii							7			

SANTALACEAE									
Exocarpos cupressiformis							7		
Leptomeria acida			3						
Santalum obtusifolium							7		9
SAPINDACEAE									
Alectryon subcinereus						6		8	
Diploglottis australis							7		
Dodonaea viscosa						6	7	8	9
Guioa semiglauca						6			
SCROPHULARIACEAE									
Veronica plebeia							7		
SOLANACEAE									
Duboisia myoporoides							7		
Solanum prinophyllum						6	7		
S. pungetium							7		
STERCULIACEAE									
Brachychiton populneum								8	
Commersonia fraseri						6	7		
Lasiopetalum latifolium							7		
STYLIDIACEAE									
Stylidium laricifolium			3				7		
S. lineare		2							
THYMELIACEAE									
Pimelea ligustrina						6	7		
P. linifolia	1								
URTICACEAE									
Australina pusilla						6			
Dendrocnide excelsa						6	7		
Elatostema reticulatum						6			
Urtica incisa						6	7		
VERBENACEAE									
Clerodendrum tomentosum						6	7		
**Lantana camara*							7		
**Verbena bonariensis*							7		
VIOLACEAE									
Hymenanthera dentata						6	7		
Viola hederacea		2							
V. sieberiana			3						
VITACEAE									
Cissus hypoglauca						6	7		
WINTERACEAE									
Tasmannia insipida						6	7		
ANGIOSPERMS — MONOCOTYLEDONS									
ANTHERICACEAE (LILIACEAE)									
Caesia vittata									9
Laxmannia gracilis									9
Sowerbaea juncea				4					
Thysanotus tuberosus				4					
ARECACEAE									
Livistona australis						6	7		
ARACEAE									
Gymnostachys anceps						6	7		
Alocasia macrorrhizos							7		
CANNACEAE									
**Canna indica*							7		
COLCHICACEAE (LILIACEAE)									
Schelhammera undulata							7		
COMMELINACEAE									
Pollia crispata						6			
**Tradescantia albiflora*							7		
CYPERACEAE									
Caustis flexuosa			3						
C. pentandra				4					
Chorizandra sphaerocephala					5				
Cyathochaeta diandra			3				7		
**Cyperus eragrostis*						6	7		
Gahnia aspera						6			
G. clarkei			3						

G. sieberana	1		3						9
Gymnoschoenus sphaerocephalus				4	5				
Lepidosperma flexuosum			3	4					
L. laterale			3	4	5		7		9
Schoenus melanostachys	1	2	3	4					
DIANELLACEAE (LILIACEAE)									
Dianella caerulea			3				7		9
D. laevis									9
D. revoluta			3						
HAEMODORACEAE									
Haemodorum corymbosum			3						
IRIDACEAE									
Libertia paniculata			3						
Patersonia glabrata			3						
P. sericea			3	4					
JUNCACEAE									
Juncus continuus	1		3						
J. sp. D$_1$			3						
J. planifolius			3	4					9
J. subsecundus			3						
LOMANDRACEAE									
Lomandra filiformis ssp. *filiformis*			3	4					
L. glauca			3	4					
L. longifolia	1	2	3			6	7		
ORCHIDACEAE									
Acianthus sp.			3						
Cymbidium suave							7		
Dendrobium linguiforme			3						
D. speciosum						6			
Liparis reflexa								8	
Pterostylis longifolia							7		
P. nutans							7		

Cunninghamia 1(3), 313–338 (1985)

A FLORISTIC SURVEY OF KU-RING-GAI CHASE NATIONAL PARK

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(Accepted for publication 28.4.1982)

ABSTRACT

Outhred, R., Lainson, R., Lamb, R. & Outhred, D. (School of Life Sciences, New South Wales Institute of Technology, Westbourne Street, Gore Hill, New South Wales, Australia 2065) 1985. A floristic survey of Ku-ring-gai Chase National Park. Cunninghamia 1(3), 313–338. A floristic classification scheme for the vegetation of Ku-ring-gai Chase National Park, New South Wales, is presented and a field key to the scheme is described. The relationship to earlier structural/floristic classification schemes is discussed. Some of the physiographic and edaphic factors underlying the floristic variations are documented. A semi-quantitative technique for collecting floristic survey data is evaluated. It appears to have some advantages when compared with conventional presence/absence recording.

INTRODUCTION

Ku-ring-gai Chase National Park is situated on the northern outskirts of Sydney, New South Wales. It is 146 km^2 in area and consists mainly of a dissected sandstone plateau bordering Broken Bay. The vegetation ranges from heath through to closed forest with rainforest elements.

There appear to be few published data relating specifically to the plant ecology of Ku-ring-gai Chase. Pidgeon (1937, 1938, 1940, 1941) made a general study of the plant ecology of the central coast of New South Wales. Beadle (1954, 1962) considered the influence of soil phosphate in determining the distribution of coastal plant communities.

Specht, Roe & Boughton (1974) surveyed the conservation status of plant communities in Australia and Papua New Guinea. They listed nine major communities for Ku-ring-gai Chase National Park, ranging, in their nomenclature, from open-forest through to low open-forest, open-scrub, open-heath, grassland/herbland and open-grassland; however, the floristic composition of those communities was not described in detail.

Buchanan (1980) has studied the freshwater swamps that occur on the West Head Peninsula and has identified areas of podzol soils within the Park.

The aims of the present project were to produce a floristically-based classification scheme for the Park's vegetation, to generate a field key to that classification scheme and to relate the floristic variations to factors such as the structural form of the vegetation and environmental parameters. It was intended that the classification scheme would summarize the range of vegetation currently present in the Park and provide a framework for future field studies. It followed that the range of vegetation sampled should be as broad as practicable and that a floristic key to the vegetation types should be developed so that unsampled areas could in the future be identified in terms of the classification scheme.

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METHODS

Selection of sampling and analysis procedures

It was necessary to select sampling and analysis techniques that were appropriate to the above aims. Considerable literature exists on the acquisition and analysis of vegetation survey data. Clifford & Stephenson (1975) reviewed progress to that time. Many authors have attempted to assess particular techniques. Williams *et al.* (1973) investigated a variety of sampling and analytical procedures with reference to rainforest vegetation. Smartt, Meacock & Lambert (1974, 1976) applied various sampling procedures to heath and grassland.

One common theme to emerge from these and other studies is that the analysis technique should be asymmetric: two sites should not be considered similar because a particular species is absent from both. As might be expected, polythetic classification techniques have been found to be superior to monothetic ones, producing fewer obvious misclassifications. Smartt *et al.* (1974) note that divisive techniques are theoretically more efficient than agglomerative ones as far as the important upper levels of a hierarchy are concerned, although this superiority has yet to be conclusively demonstrated in practice. Lambert *et al.* (1973) reported good results from their polythetic divisive algorithms AXO and MONIT, while our own limited experience has been that indicator species analysis (ISA) described by Hill, Bunce & Shaw (1975) performs at least as well on field data as flexible sorting (Lance & Williams, 1967), one of the more commonly used agglomerative techniques.

Indicator species analysis was selected for the present application. ISA is a polythetic divisive technique that sorts the quadrats into a dichotomous hierarchy. ISA is insensitive to species richness; a quadrat is evaluated according to the average affinities of the species that it contains, irrespective of their total number. In the course of the classification procedure ISA produces a polythetic key to the hierarchy in terms of indicator species. Moreover, ISA orders both quadrats and species before each division, facilitating the subsequent production by the computer of diagonalized association tables.

There appears to be a general consensus that in order to produce a phytosociological classification, the sampling and analysis procedures should avoid situations where a few species dominate the data from a site. Smartt *et al.* (1976) and Strahler (1978) found little benefit in departing from simple presence/absence data. On the other hand, Williams *et al.* (1973) concluded that quantitative data yielded a superior classification of rainforest vegetation provided that the analysis techniques prevented very abundant species from exerting a dominating influence.

For the present project we decided to test a variant of the traditional presence/absence sampling procedure. Under the procedure adopted, a large quadrat is subdivided into concentric subquadrats. Species are recorded from the central subquadrat and then additional lists are made of new species appearing in each of the succeeding subquadrats.

The use of the concentric subquadrats follows a suggestion by Bunce & Shaw (1973). The procedure promotes a systematic search of the quadrat and allows considerable flexibility in comparisons with other surveys based on different sized quadrats. It is as economical of survey effort as the normal presence/absence recording procedure and is thus much more economical than any of the traditional quantitative approaches. However, it has the theoretical advantage over the presence/absence method that in an area of homogeneous vegetation, species that occur in the inner subquadrats are likely to be those that are most abundant in the area. That is, the method can be semi-quantitative; some information relating to abundance is retained. On the other hand, if the quadrat is sited on an ecological gradient, then the centrally occurring species will best typify one particular point on the gradient. In either case there may be an advantage in according the inner-subquadrat occurrences higher weight in the subsequent analysis. In order to test whether the postulated advantage would be realized in practice, analyses of the data were performed with and without extra weighting for inner-subquadrant occurrences.

Data acquisition

At each site to be sampled, a square 1000 m² quadrat was delineated by means of four corner pegs connected by diagonal cords to a central peg. Markers on the cords divided the total quadrat into eight square concentric subquadrats of cumulative area 5, 10, 20, 50, 100, 200, 500 and 1000 m² (Figure 1). These subquadrats will be designated by the numbers 1 (central) to 8 (outermost). Species occurrences were recorded progressively, commencing with subquadrat 1 and noting for each species the subquadrat in which it was first encountered.

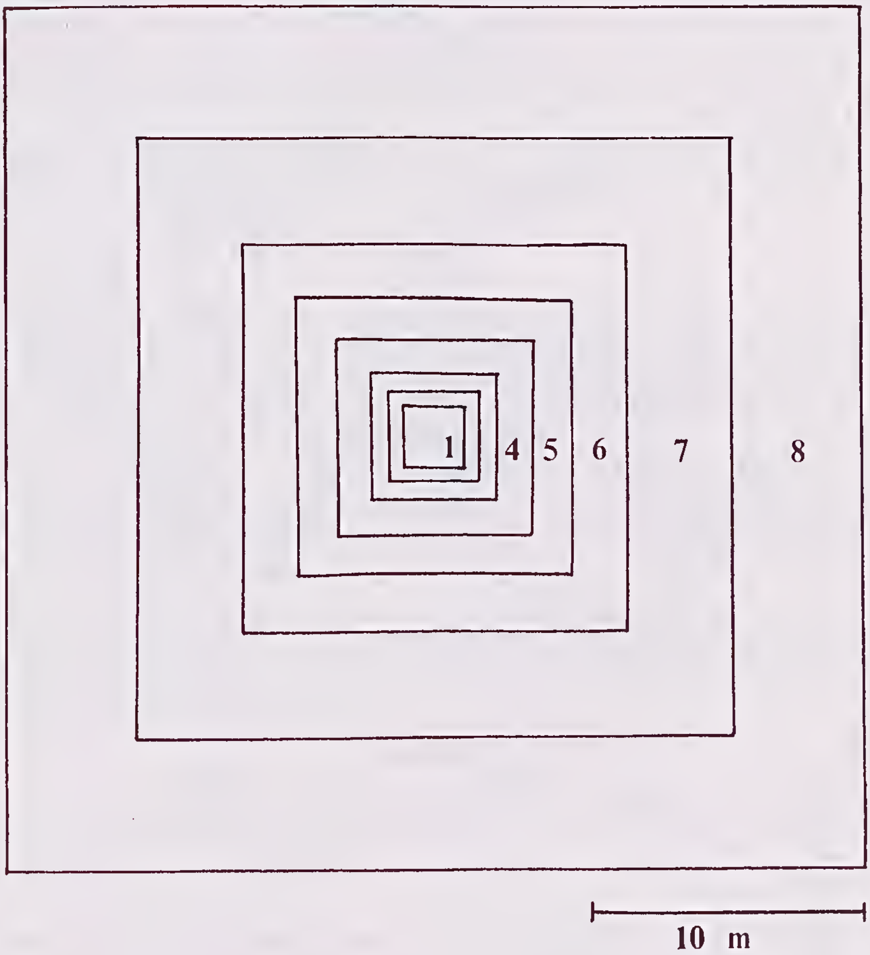


Figure 1. Division of quadrat into eight subquadrats.

The quadrats were considerably larger than the 200 m² ones used by Bunce & Shaw (1973) in European grassland and woodland. In the absence of any firm evidence as to what would be an adequate quadrat size in this situation, we elected to use as large an area as practicable to ensure that sufficient information was collected from each site. The adoption of the nested-subquadrat system meant that smaller quadrats could be used if desired in any supplementary surveys. It also enabled the effective quadrat size to be varied in the analysis.

The floristic data set encompassed all classes of tracheophytes. Normally, plants were differentiated to species level. The few exceptions concerned species that were difficult to distinguish reliably on vegetative characters. Where we were not certain of having correctly resolved such species in every quadrat, they were aggregated for the purpose of the indicator species analysis or, in the case of a few infrequently encountered Cyperaceae, excluded from it.

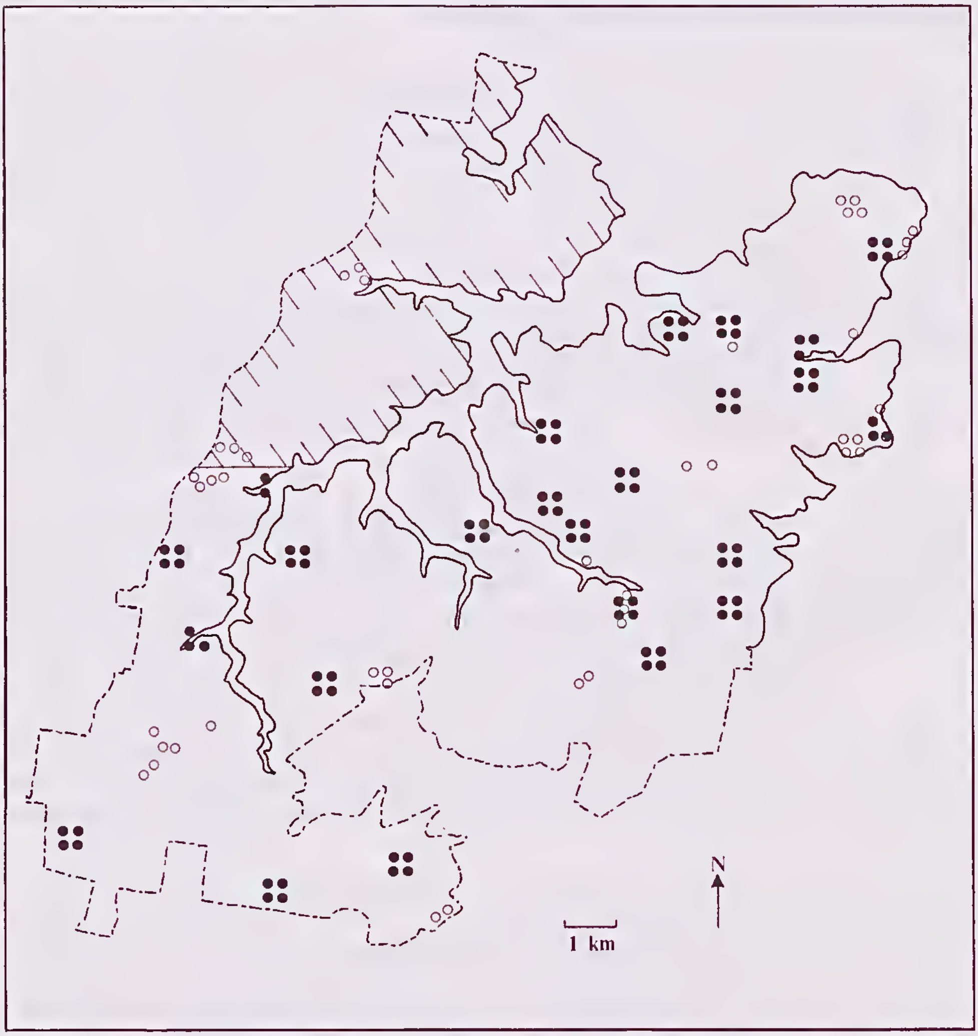


Figure 2. Locations of the sampling sites within Ku-ring-gai Chase (filled circles denote set 1 sites, open circles set 2 sites; the shaded zone in the north-west of the Park was excluded from survey in set 1).

Authorities for names of angiosperms used in this paper are listed by Jacobs & Pickard (1981). Fern names are as used by Beadle, Evans & Carolin (1972).

Estimates were made at each site of several structural features — tree height and cover, shrub cover and herb cover. All cover estimates were subjective. Some features of the physical environment were noted — altitude, slope, aspect and percentage rock outcropping. The type of rock was recorded.

Two sets of sites were surveyed. The first set comprised 91 sites, positioned randomly on a grid. The second set of 43 sites was designed to obtain additional samples from areas of limited extent possessing special environmental features. It included four sites on dolerite, five on Wianamatta Shale at Duffys Forest and Terrey Hills, five on or near podzolized soils, 13 along stream margins and 10 adjacent to salt water. The overall distribution (Figure 2) was designed to sample as broad a range of vegetation as practicable while also acquiring data on the abundance of species and vegetation types.

Sites in the first set were located in groups of four at the apices of 300 m squares centred in randomly selected 0.5 km squares of a cartographic grid (Figure 3). Sites that would have fallen below the high tide mark or outside the Park were excluded. Each group of four sites could be visited in one day but the members of the group were sufficiently separated to sample a range of habitats. An area of 27 km^2 north of Berowra and west of Cowan Creek (Figure 2) was excluded from sampling in set 1 because of access difficulties. However, six sites in set 2 were located in that area.

For both sets of sites, the final locations of the quadrats on the ground were either predetermined or randomized. Care was taken **not** to deliberately select supposedly representative stands.

Analysis

A program to perform ISA was written in FORTRAN for an ICL 1904 computer. Analysis to 32 groups required 30 to 60 minutes of processor time. The program was designed primarily for presence/absence data, but occurrences could, when necessary, be weighted by repetition. A companion program generated association tables for species against quadrat groups.

Other programs were written to summarize statistically the structural and environmental data for the quadrat groupings produced by the classification procedure and to list descriptive summaries of nominated groups of quadrats from a master file of such descriptions.

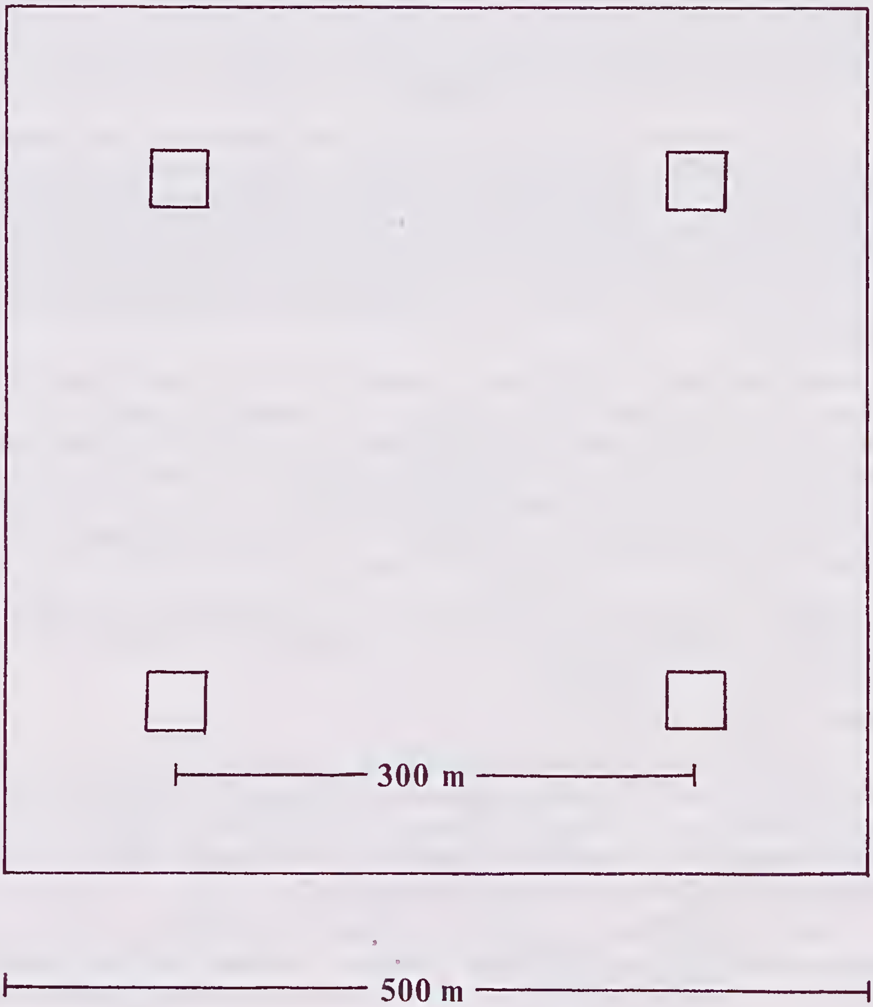
Four classifications of the floristic data were performed to investigate the benefits of including data from the outer subquadrats and according higher weights in the analysis to species occurring in central subquadrats. The essential parameters of the analyses are shown in Table 1.

TABLE 1

Parameter settings for the four ISA classifications

Analysis no.	Effective quadrat size (m^2)	Subquadrat weights	Rarity threshold
1	50	equal	20
2	1000	equal	20
3	1000	4:4:3:3:2:2:1:1	40
4	1000	4:4:3:3:2:2:1:1	80

Figure 3. Position of set 1 quadrats within an 0.5 km grid square.



Analysis 1 was confined to occurrences in the inner four subquadrats; effectively the analysis was based on equally weighted presences in 50 m² quadrats. Analysis 2 assigned equal weight to all occurrences in the entire 1000 m² quadrats. In the third and fourth analyses, subquadrats 1 to 8 were weighted in the ratio 4:4:3:3:2:2:1:1.

ISA has one adjustable parameter, the threshold of rarity (Hill *et al.*, 1975). Its effect is roughly analogous to that of β in the flexible-sorting strategy of Lance & Williams (1967). A high rarity threshold, like a negative β, causes groups to be more evenly sized. A traditional value for presence/absence data is 20 per cent of the number of quadrats. This value was adopted for analyses 1 and 2. To achieve a comparable effect with multi-level data, a higher value must be used. The threshold was therefore increased to 40 per cent for analysis number 3. To check whether the necessarily somewhat arbitrary value of the rarity threshold was critical, a fourth analysis was performed using an 80 per cent threshold.

RESULTS AND DISCUSSION

Evaluation of subquadrat weighting schemes

The classification schemes produced by the four analyses of the data set were first compared by examining how they had dealt with three special groups of sites. The outcropping rock in the Park is predominantly sandstone of the Hawkesbury Series. However, five sites from set 2 were located on the overlying Wianamatta shales in the south of the Park, near Duffys Forest and Terrey Hills, and four other sites were on eroded dolerite near West Head. These provided two edaphically distinct groups. The third special group of sites sampled stream margins in the deep valleys, a physiographically distinct habitat.

There is no reason why these groups must be floristically distinct from other surveyed sites and, if they are not, then not even a "perfect" analysis technique would isolate them, but if one technique did succeed in isolating them while another did not, it would seem reasonable to consider the former technique superior.

Analysis 1, based on data from a 50 m^2 quadrat, did not isolate any of the groups. Increasing the quadrat to 1000 m^2, as in analysis 2, enabled the Wianamatta Shale and dolerite sites to be extracted successfully. Finally, analyses 3 and 4, which used information from the entire 1000 m^2 but accentuated the inner subquadrat occurrences, isolated stream margins as well.

We conclude from these results that presence/absence data from a single 50 m^2 quadrat does not adequately characterize the types of vegetation sampled here. Increasing the quadrat area to 1000 m^2 produces a useful increase in information but the additional data can be distracting when dealing with situations such as stream margins where the quadrat is located in a pronounced environmental gradient. This can be corrected by increasing the weight accorded to the inner-subquadrat data. The data from the outer subquadrats then provide a floristic context without confusing the local ecological picture defined by the inner subquadrats. That there is value in recording the context is evidenced by the superiority of analyses 3 and 4 over analysis 1 in dealing with stream margins.

There are other regions within the Park that have reasonably distinct vegetation without, however, being associated with such clearly defined physical and edaphic features as were the three discussed above. Three of the most obvious are: areas of wet heath usually associated with impeded drainage on hillsides; dry *Casuarina* forests on steep hillsides; and marginal rainforest at low altitudes with *Acmena smithii* and *Ceratopetalum apetalum* in the canopy. In fact, all of these areas were extracted by analyses 3 and 4 as floristically distinct units. Analyses 1 and 2 were less successful.

In general, the groupings produced by analyses 3 and 4 were more readily interpreted than those resulting from numbers 1 and 2, particularly number 1.

An alternative approach to evaluating the analyses is to consider the environmental and structural homogeneity of the groups they produce. It would seem reasonable to prefer the analysis that sorts the sites into groups whose members are most similar in terms of vegetation structure and environmental factors.

Analyses of variance were performed to assess the homogeneity of the site groups in terms of six environmental factors: altitude, aspect, slope, rock cover, east-west location and north-south location; and five structural factors: canopy height, tree diameter, tree cover, shrub cover and herb/fern cover. To permit intercomparisons, standardized conditions were necessary — for each classificatory analysis, the site groups considered were the 16 produced by four levels of dichotomous division. The ratio of the between-groups to within-groups variance was computed for each of the 11 factors, the computations being repeated for the four sets of site groups arising from the different classificatory analyses.

The resulting 44 variance ratios were all significantly greater than one (F-test, $p<0.01$); all four floristically-based analyses were significantly related to all the 11 non-floristic factors.

The strengths of the relationships were then examined. Paired-sample t-tests did not reveal any significant differences between the variance ratios derived from analyses 3 and 4, either when all 11 factors were considered together or when structural and environmental factors were considered separately. The figures for analyses 3 and 4 were therefore pooled in subsequent comparisons with analyses 1 and 2. Analyses 1 and 2 performed worse overall than did analyses 3 and 4 ($p<0.01$). Analysis 1 was inferior in its treatment of the environmental parameters and analysis 2 in its treatment of the structural parameters.

In summary, it was beneficial to use the large quadrats, provided that increased weight was given to species encountered near the centres of the quadrats.

The weights adopted (Table 1) were linearly related to the logarithm of the area (rounded to integer values). They were a necessarily arbitrary selection from the infinity of possible sets of weights and the question arises as to whether further benefits might have been gained by giving central occurrences even greater emphasis. The present data are not sufficiently extensive to allow this question to be answered reliably. However, one effect would have been to increase the importance of small but abundant plants. In the extreme, that would have been likely to adversely bias the classification.

It is likely that the above conclusions will prove to be applicable to other types of vegetation. A subjective assessment of unpublished analyses of two other data sets, one from subalpine forest and heath on the Boyd Plateau west of Sydney and the other from an upland moorland area in northern England, suggests that in both of those situations there was an advantage to be gained from emphasizing central occurrences or locally abundant species.

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Altogether, 365 species were recorded from the 134 quadrats. The number of species per quadrat ranged from 22 to 136.

Analysis 3 was selected as the basis for the final classification scheme. The classification process was continued through five levels of dichotomous division, generating a dendrogram with 2^5 ultimate branches. The floristic, structural and environmental parameters of the sites in the 32 ultimate groups were critically examined and field testing of the classification scheme was performed. In several instances, little ecological meaning was discernible in the lowest dichotomies and/or the group populations were very small. In these areas the relevant sectors of the dendrogram were truncated above the final division. This left 23 groups that we considered distinguishable not only floristically but usually also on the basis of the vegetation structure and habitat requirements.

The above result is necessarily a compromise between the opposing risks of discarding worthwhile information or retaining meaningless distinctions. Arguably more or fewer than 23 groups could have been retained. Some of the distinctions preserved are based on few quadrats, albeit supported by subsequent field trials, and must be considered tentative.

An alternative strategy would have been to invoke a numerical stopping rule. However, many such rules exist and the selection of a particular one would perforce be no less subjective and arbitrary than the procedure actually adopted. They have not always been found entirely satisfactory in practice (Siddiqui, Carolin & Anderson, 1972) and have not traditionally been used with ISA.

For purposes of discussion we shall regard the 23 quadrat groups as samples from corresponding vegetation types. The properties of the 23 types are inferred from the observed properties of the groups. The groups' floristic properties are summarized in Table 2. Table 3 shows the affinities of the common tree species. The structural and physiographic properties are detailed in Table 4.

There are two widely used structural/floristic classification schemes for Australian vegetation (Specht *et al.*, 1974 and Carnahan, 1976). The present floristically derived classification scheme proved to be strongly correlated with structural variations. These correlations encouraged us to attempt to describe the upper divisions within the classification scheme in terms of their structural correlates, with the results shown in Table 5.

Our structural terminology is defined in Table 6. It is broadly consistent with that of Specht *et al.* (1974), but height and cover are more finely partitioned and we have elected to describe vegetation with light tree cover and dense shrub cover as belonging to the appropriate shrub class but with emergent trees.

The correlation between floristic and structural characters is not perfect. Therefore, our structural or environmental descriptors applied to a floristically derived classification scheme typify rather than define. The descriptors applied to the lower divisions in particular should be regarded as tentative.

We recognize five series of floristic types. Each series corresponds to a particular sector of the hierarchy. We denote the series as S (scrub/heath), L (low woodland or open forest), M (moderately low open forest), MT (medium or moderately tall sclerophyll forest) and R (marginal rainforest).

The five series represent gradations along the major trend in the data — from heath and scrub to closed forest. The S, L and M series are characterized by the presence of the tree *Eucalyptus gummifera* and a variety of shrubs such as *Leptospermum attenuatum, Platysace linearifolia* and *Xanthorrhoea media. Casuarina torulosa, Pteridium esculentum* and *Dianella caerulea* are often present at MT and R series sites.

FOOTNOTE TO TABLE 2

The symbols used to denote the quadrat groups are explained in the text. The species have been arranged in order of their scores on the first axis of a reciprocal averaging ordination. The quadrat groups have likewise been ordered according to the mean scores of their members on the same ordination, insofar as this has been possible without overlapping adjacent sectors of the classificatory dendrogram. The Table was compiled from mean occurrence-scores for the species in the quadrat groups. Occurrences were scored in the manner used in the classificatory analysis, viz: first encountered in the subquadrats 1 or 2: 4, 3 or 4: 3, 5 or 6: 2 and 7 or 8: 1. An entry of + + + indicates a mean occurrence-score of at least 3.5; that is, the species was nearly always encountered within subquadrats 1 and 2 in quadrats belonging to that group. The other symbols indicate the following ranges: + +: 3 to 3.5; +: 2 to 3; ■: 1 to 2. Lesser scores are blank. Species have been included only if they achieved a + + + score in at least one quadrat group.

TABLE 2

Abundance of species in quadrat groups

	S1	S2	S3	S4	L1	L2	L3	M1	M2	M3	M4	M5	M6	M7	MT1	MT2	MT3	MT4	MT5	R1	R2	R3	R4
Acmena smithii																				+++	+++	+++	+
Ceratopetalum apetalum																				++	+++	+++	+++
Blechnum cartilagineum																			.	+++	++	++	.
Tristania laurina																				.		.	+++
Lomatia myricoides																				.		.	+++
Synoum glandulosum																		+++	++	++		.	.
Oplismenus aemulus																+	+++	.	+	++			.
Sticherus flabellatus																					+++		+
Eustrephus latifolius																.	+	++	+	+++	++		
Hibbertia dentata																	++	+++	+	+			
Pittosporum undulatum																				.	+++		
Pandorea pandorana																.	.	+++	.	+	.		
Glycine clandestina																	.	+++	+	.	.		
Acacia floribunda																		+++	.	.	.		
Clematis glycinoides																		+++					
Macrozamia communis																		+++					
Casuarina torulosa														.		+	+++	.	+	+	.	.	+
Culcita dubia														.	.	.	.	.	+++	+++	+	+	.
Astrotricha floccosa																+		+		+++	.		
Themeda australis										+						.	+++	+		.			
Lomandra longifolia								.			.	.	.	+	++	+	+++		+++	+++	+++	.	.
Dianella caerulea							.	.	+	.	.		+	++	++	+++	+	+	+	.	+++	+	+
Pteridium esculentum								.	.	++	+	++	+	++	++	+++	+++	+++	++	+++			
Entolasia stricta		.				.	+	+	+++	+		++	.	++	+	+++	.	++		+	+		.
Lepidosperma laterale	.	+	+	+++	.	+	.	.	++		+	+		++	+	+	+	.		.			
Caustis flexuosa		.					+	+			.	+++	+	+	+					.			
Persoonia levis		.			.	.	+	+	.	+++	.	+	+	+	.								
Hibbertia bracteata		.		++	+	.	+	.		+++	.	+	.	.									
Patersonia sericea	.	+	+	.	++	++	.	++	++	+++		++	.					+					
Micrantheum ericoides					.	.	+	+	+	+++			.										
Banksia serrata		.	+		++	+	+	+	.	++	++	+++	+	++	.								
Acacia suaveolens	.			+++	.	+	.	+			+	.	.	.	+								

	S1	S2	S3	S4	L1	L2	L3	M1	M2	M3	M4	M5	M6	M7	MT1	MT2	MT3	MT4	MT5	R1	R2	R3	R4
Acacia myrtifolia										+++													
Lomandra glauca		+	+	+	+	+++	.	+++	+++	++	+++	+++	.	.									
Platysace linearifolia	.	+	+	+	++	+	+++	++	+++	+++	+	+++	++	.		.							
Leptospermum attenuatum	+	+++	++	++	+++	+++	+++	+++	++		+++	+++	+	+	.	.				.			
Grevillea sericea	.	+			++	+	++	++	+			.	+++	.	.					.			
Eucalyptus gummifera		+	+	.	++	+++	++	++	.	+	+	+	+	.		.							
Dillwynia retorta	.	+++	+	+++	+++	++	++	+++			+	+	++	++									
Boronia pinnata	.	+++	.	.	+++	.	+	++		+++	+	.	+	.	.								
Xanthorrhoea media	+++	+++	+++	+	+++	+++	+	+	+	.	++	++	+	.									
Pultenaea elliptica	.	+	++	+	+	+	+++	+				+	.										
Phyllota phylicoides		+	+++	+	++	+++	+	++	.	.	+	.	.	.									
Petrophile pulchella	+	+++	.	.	++	+	+	+	.	.	.	++	+										
Lambertia formosa	.	+++	+	.	++	+	++	+	+	+	.	+	.										
Dampiera stricta	++	+			+++	+	+	++	++	.	.	.	+										
Conospermum longifolium		.			++	+	.	+	+	++			.										
Lepyrodia scariosa	+	+++	++	+++	++	++	+++	+	.			+	+										
Dillwynia floribunda	+++	.				.			.		.	++											
Bauera rubioides	+++	.	.	.			.							.									
Banksia ericifolia	+++	++	+++	+	++	+	+	.				.	.			.							
Actinotus minor	+	++	++	+++	+++	+++	+++	+++			.		+	.									
Schoenus imberbis		.	+++	+++	.	.	.				.												
Leptospermum squarrosum	+++	.	.	++			+					.											
Isopogon anethifolius	.	+	+	+++	.	+	.						.										
Hakea teretifolia	+++	+++	+++		+	.	+++					+	.										
Cyathochaeta diandra	++	++	+++	+	+	+	+	+	++	+++	.												
Phebalium squamulosum				+++																			
Leucopogon microphyllus	+	+++	+++	+++	+++	+++	++																
Casuarina distyla	.		+++	+++		.																	
Grevillea speciosa	+++	++	+	+++			.					.											
Epacris microphylla	+++	.	+	+			.					.											
Caustis pentandra			+	+++		.																	
Mirbelia rubiifolia		.		+++																			
Kunzea capitata	++	+	+	+++	.	.																	
Banksia aspleniifolia	+++	+	++	.	+	.	+																
Stylidium lineare	+	+++	+																				

TABLE 3

Abundance of tree species in the quadrat groups

	S1	S2	S3	S4	L1	L2	L3	M1	M2	M3	M4	M5	M6	M7	MT1	MT2	MT3	MT4	MT5	R1	R2	R3	R4
Acmena smithii																				+++	+++	+++	+
Ceratopetalum apetalum																				++	+++	+++	+++
Tristania laurina																				.		.	+++
Lomatia myricoides																				.		.	+++
Callicoma serratifolia																					.	+	+
Acacia elata																						.	
Pittosporum undulatum																				.	+++		
Eucalyptus botryoides																			.	.			
Eucalyptus paniculata																			.				
Casuarina torulosa														.		+	+++	.	+	+	.	.	+
Angophora floribunda																.	+		.				
Syncarpia glomulifera												.		.				++	.				
Eucalyptus umbra				.		.			.		.	.		.	+			+					
Eucalyptus piperita								.			.	+	+	+	.			.					
Angophora costata				.			.	+	+	+	.	+	+	+	++								
Casuarina littoralis								+	+	+						+	.						
Eucalyptus racemosa									.														
Eucalyptus sieberi								.		+													
Eucalyptus punctata				.					.														
Eucalyptus gummifera		+	+	.	++	+++	++	++	.	+	+	+	+	.		.							
Eucalyptus haemastoma	.	+	.	.	.		.			.													
Eucalyptus oblonga		.			.																		
Casuarina distyla	.		+++	+++		.																	
Angophora hispida	+	+	+		.																		

FOOTNOTE TO TABLE 3

Callicoma serratifolia, *Lomatia myricoides*, *Casuarina distyla* and *Angophora hispida* have been classified as trees for the purpose of this Table. The ordering of species and quadrat groups and the scaling of abundance are as described for Table 2.

The S series

The first split within the S series appears to relate to drainage characteristics and correlates well with the amount of outcropping rock, rocky areas generally being better drained. The less rocky group then divides into types S1 (wet closed heath) with *Leptospermum squarrosum, Epacris obtusifolia* and *Bauera rubioides* and type S2 (dry scrub) often with emergent *Eucalyptus gummifera* and *E. haemastoma.*

The distinction between S3 and S4 is necessarily tentative as S4 was representated by only two quadrats. However, subsequent field experience suggests that the distinction is meaningful, type S4 occurring in rockier and more exposed situations.

The L series

The L series contains three types. Type L1 tends to occur on low-rock, low-slope sites on or near broad ridges. It has floristic affinities with S2 (dry scrub) but lacks some of the heath plants such as *Stylidium lineare* and *Grevillea speciosa* and contains open forest species such as *Banksia serrata, Bossiaea heterophylla* and *Hibbertia bracteata.* Type L2 is associated with rockier areas, often above low cliffs. *Eucalyptus umbra* is often present. Type L3 is typically found slightly further from the ridgetops. Seepage zones bear species such as *Leptospermum squarrosum, Bauera rubioides* and *Lepyrodia scariosa.*

The M series

Angophora costata is typical of M-series sites. *Eucalyptus gummifera* is usually also present. The first division within this series separates the Wianamatta Shale sites (floristic type M3) and the related types M1 and M2 from forest on more or less sheltered sandstone slopes. We have tentatively described the M1 and M2 types as "shale influenced and/or drier". They sometimes occur on ridgetops or benched hillsides where the presence of nearby shale bands may be surmised, although the outcropping rock may be sandstone. These vegetation types can be found on sandstone ridges leading east from the Wianamatta Shale at Mt Ku-ring-gai, but on similar ridges further to the north or east they are replaced by the more stunted vegetation of types L1 and L2.

Micrantheum ericoides, Phyllanthus thymoides, Lomatia silaifolia, Casuarina littoralis and *Lasiopetalum ferrugineum* were more prevalent in the quadrats allocated to types M1 to M3 than at most other sites.

The survey quadrats classified as M3 were all situated on Wianamatta Shale near Terrey Hills or Duffys Forest. *Eucalyptus sieberi, Acacia myrtifolia* and *Bossiaea obcordata* are usually present in M3 vegetation, the last being the most faithful. *Eucalyptus sieberi* forest on a shale lens where the West Head road crosses Salvation Creek is closely related floristically, but shale lenses within the Hawkesbury sandstones do not always so detectably influence the vegetation.

Types M4 to M7 occur on sandstone slopes. Particularly in the case of type M7, the site is steep, well drained, and is often south-facing. The most common trees are *Angophora costata, Eucalyptus gummifera* and *E. piperita. Stylidium productum, Pteridium esculentum, Xanthosia pilosa, Caustis flexuosa* and *Woollsia pungens* are also frequent. There is a gradation from M4, which contains species with ridgetop affinities (e.g. *Phyllota phylicoides*), through to M7, which is mostly found on lower slopes with *Dodonaea triquetra.*

TABLE 4

Group averages of physiographic factors, structural properties and species numbers

DATA FROM SET 1 SITES

	S1	S2	S3	S4	L1	L2	L3	M1	M2	M3	M4	M5	M6	M7	MT1	MT2	MT3	MT4	MT5	R1	R2	R3	R4	MEAN	SD
Number of sites	8	7	6	2	8	8	10	7	4	0	3	5	6	4	3	5	1	0	2	2	0	0	0		
East-west coordinate			+					--		*		+						*	++		*	*	*	355	46
North-south coordinate								-		*		++						*	++		*	*	*	768	33
Slope (degrees)		-			-					*			++				++	*			*	*	*	15	10
Aspect: angle from north		+								*					++			*		++	*	*	*	91	63
Altitude (m)						+				*		-				--	--	*	--	--	*	*	*	108	43
Rock cover (%)			+	++	-			-		*			++					*			*	*	*	19	17
Canopy height (m)	--	-	--	--	-			+		*		+	+	++	++	+		*	++	++	*	*	*	11	6
Tree diameter (cm)	--	-	--	--	-					*				++	+			*	++	++	*	*	*	51	37
Tree cover (%)	--	-	--	--						*				++	++	++		*	++	++	*	*	*	36	21
Shrub cover (%)							+			*		+		+			--	*	--		*	*	*	65	25
Herb and fern cover (%)					-			-		*	-							*	++		*	*	*	24	21
species in quadrat							+	+	--	*			+			--		*	--		*	*	*	58	14

DATA FROM ALL SITES

	S1	S2	S3	S4	L1	L2	L3	M1	M2	M3	M4	M5	M6	M7	MT1	MT2	MT3	MT4	MT5	R1	R2	R3	R4
Number of sites	8	7	6	2	9	10	10	7	5	5	8	5	8	7	4	5	5	4	3	3	2	4	7
East-west coordinate			+					--		-		+						++	++			--	
North-south coordinate								-		--	+	++					++	++				--	
Slope		-			-	-				--				+			++						
Aspect: angle from north		+								-				+			-			++	++		
Altitude					+	+				++	+	-				--	--	++	--	--	--	--	--
Rock cover			+	++	-			-		--			+					--				++	++
Canopy height	--	-	--	--	-			+		+	+	+	+	++	++	+		++	++	++	++		++
Tree diameter	--	-	--	--	-	-								+	+				++	++			
Tree cover	--	-	--	--										++	++	++		++	++		++	++	++
Shrub cover							+					+		+		-	--		--		--	--	--
Herb and fern cover					-			-		+	-			-				++	++			-	-
species in quadrat							+	+	-	-	-					--	--		--		--	--	-

TABLE 5

The hierarchical classification scheme derived from the floristic data, interpreted as far as possible in terms of the associated environmental and structural trends

SERIES S: SCRUB/HEATH, with or without emergent low trees	less rocky; poorly drained	wet closed heath	S1
		dry scrub	S2
	rocky; well drained	rocky	S3
		very rocky	S4
SERIES L: LOW WOODLAND, with dense shrub layer	dry; on or near ridges	broad ridges & slopes	L1
		rocky spurs & slopes	L2
	on seepage zones, e.g. under minor cliffs		L3
SERIES M: MODERATELY LOW OPEN FOREST	shale & shale-influenced or drier	species rich	M1
		species poor	M2
		Wianamatta shale	M3
	more or less sheltered sandstone hillsides, often with seepage zones	upper slopes	M4
			M5
			M6
		lower slopes	M7
SERIES MT MEDIUM OR MODERATELY TALL SCLEROPHYLL FOREST	on sandstone	WSF	MT1
		DSF; Casuarinas	MT2
	on dolerite, or on shale-influenced sites on lower slopes	DSF; Casuarinas	MT3
		WSF; on dolerite	MT4
		WSF; sheltered slopes	MT5
SERIES R: MARGINAL RAINFOREST medium or moderately tall, canopy more or less closed	sheltered slopes	WSF/RF	R1
		RF	R2
	stream-side gallery forest		R3
			R4

FOOTNOTE TO TABLE 4

The first part of the Table is based on the 91 random-grid sites comprising set 1. A + or − symbol denotes that a t-test or, when the data derived from less than three quadrats, a direct computation of probability, indicated a probably substantive difference between the group mean and the set 1 mean shown in the right-hand columns. The significance level was nominally 5 per cent; however, with survey data, possible spatial coherence precludes a precise interpretation. Duplication of the symbol indicates that in addition to meeting the above criterion, the difference exceeded the set 1 standard deviation. Asterisks denote groups for which no set 1 data were available. The second part of the Table contains equivalent data derived from set 1 and set 2 combined. As before, comparisons are with the set 1 means. In the 10 groups that included members from both set 1 and set 2, differences between the set 1 and set 2 groups means did not exceed those anticipated through chance.

TABLE 6

The relationship of the structural terminology used in the present paper to that of Specht et al. (1974) and Carnahan (1976)

STRUCTURAL CHARACTER	DESCRIPTOR		
	Specht et al	Carnahan	Present Paper
a) Height of tallest stratum (metres); trees present			
> 30	tall	T	tall*
20 - 30	no prefix	M	moderately tall*
15 - 20	no prefix	M	medium*
10 - 15	no prefix	M	moderately low*
< 10	low	L	low*
b) Height of tallest stratum (metres); trees absent, shrubs present			
> 2	scrub or shrubland#	S	scrub or shrubland#
< 2	heath or low shrubland#	Z	heath or low shrubland#
c) projective cover of tallest stratum (%); trees present			
< 10	open woodland	1	sparse woodland*
10 - 30	woodland	2	woodland*
30 - 50	open forest	3	open forest
50 - 70	open forest	3	forest
70 - 100	closed forest	4	closed forest
d) projective cover of tallest stratum (%); trees absent, shrubs present			
< 10	open shrubland	1	sparse shrubland
10 - 30	shrubland	2	shrubland
30 - 50	open scrub/heath	3	open scrub/heath
50 - 70	open scrub/heath	3	scrub/heath
70 - 100	closed scrub/heath	4	closed scrub/heath

* If tree cover is less than 30% and shrub cover is much greater than tree cover, name in terms of shrub layer and add the qualifier: 'with emergent trees'.

# Shrubland if shrub cover is less than 30%.

The MT series

The medium or moderately tall forests of the MT series are mainly confined to the middle and lower slopes. An important exception is the area of MT4 vegetation on dolerite near West Head. Trees often present on MT sites include *Casuarina torulosa, Angophora floribunda* and *A. costata.*

Type MT1 represents an extension of the continuum underlying types M4 to M7. Common trees are *Angophora costata* and *Eucalyptus umbra.* MT1 typically occurs on well drained south or east-facing slopes.

Type MT2 is a drier forest on slopes that are often steep and of northerly aspect. *Casuarina littoralis* and *C. torulosa* dominate the canopy and there is an open shrub layer.

Type MT3 has strong affinities with the preceding type. However, *Casuarina torulosa* is much more prevalent than *C. littoralis,* and the shrub layer is even more open and contains fewer "ridgetop" species. MT3 occurs at very low altitudes, being common on north-east and north-west slopes fronting Pittwater and Cowan Creek. It is often associated with shale of the Hawkesbury or Narrabeen series.

The two remaining types in the MT series, MT4 and MT5, have open to very open shrub layers and a ground cover containing many ferns. We have recorded MT4 only from the dolerite near West Head. *Syncarpia glomulifera* is frequent and *Macrozamia communis* occurs in the understorey. MT5 occurs on east-facing sites above Pittwater. There are many species in common with MT4. *Angophora floribunda, Eucalyptus botryoides* and *E. paniculata* are more frequent in the canopy and the shrub layer is even more open. *Culcita dubia* and *Lomandra longifolia* are prevalent. Like MT3, type MT5 may be associated with shale.

The R series

The forests of the R series have the rainforest species *Ceratopetalum apetalum* and *Acmena smithii* in the canopy. The shrub cover is low, as too is the count of species in a 1000 m² quadrat. The principal dichotomy within the series separates stream-side gallery forests (R3, R4), with, for example, *Tristania laurina, Lomatia myricoides* and *Hymenophyllum cupressiforme,* from forests on sheltered hillsides above salt water (R1, R2), typically containing *Eustrephus latifolius* and *Cissus hypoglauca.* The distinction between R1 and R2 is based on few quadrats, but field experience indicates that it is meaningful, R2 having stronger rainforest affinities. R3 vegetation frequently contains the exotic species *Ligustrum sinense* and *Ageratina riparia,* which were not found at R4 sites. At present, we have recorded R3 only in the south-west of the Park from streams whose headwaters have been affected by urban development.

Relative abundance of the floristic types

The relative areas covered by the different floristic series can be estimated from the numbers of quadrats from set 1 classified into each category, since those quadrats were positioned on a randomized grid. The results are shown in Table 7. The S, L and M floristic series are all widely distributed and among them cover around 85 per cent of the region surveyed by set 1, whereas the marginal rainforests of the R series cover only a few per cent. Type M3, associated with Wianamatta Shale, and type MT4, associated with dolerite, are also very restricted in distribution, reflecting the scarcity of the relevant parent rocks.

Small areas of freshwater swamp occur within the Park. No set 1 quadrat fell within a swamp. They were not sampled in set 2 as a study of the swamp vegetation has been reported elsewhere (Buchanan, 1980).

Mangrove communities also exist within the Park. They are floristically very simple, containing only *Avicennia marina* and *Aegiceras corniculatum* in the canopy. They were excluded from the present survey, which was restricted to the strictly terrestrial vegetation.

Local areas of podzol soil within the Park have been identified by Buchanan (1980). Four set 2 quadrats were placed on such areas and one on an adjoining area

TABLE 7

Percentages of the 91 set 1 sites classified into the various floristic series

Series	S	L	M	MT	R
Percentage	25	29	32	12	2

TABLE 8

Floristic affinities of four quadrats placed on podzolized sites identified by Buchanan (1980) and one placed on a topographically similar non-podzol site adjoining Buchanan's podzol number 4

Soil	Buchanan's reference no.	Floristic type
Podzol	24	MT1
Podzol	14	M4
Podzol	12	M4
Podzol	4	M7
Non-podzol	—	M6

with non-podzol soil. As shown in Table 8, the similarities among the podzol sites were not sufficiently strong for the analysis to assign them all to a single type. However, they were all placed within the continuum of types M4 to MT1, which were typically found to occur on well drained, often south-facing, sandstone slopes, whereas the podzols sometimes occurred in more level, more exposed sites.

Occurrences of exotic plants

Fourteen species of exotic plants were recorded from the 134 survey quadrats, 4 per cent of the total number of species encountered. No doubt the figure would have been considerably higher if disturbed areas such as roadsides, picnic places, etc., had been surveyed.

The exotics were unevenly distributed among the floristic types as indicated in Table 9. Type MT3 (*Casuarina* forest) and the marginal rainforest types of the R series were the most affected. No exotics were found in any quadrat assigned to series S (heath and scrub) or L (low woodland), and very few in series M (moderately low open forest).

The uneven distribution probably reflects the inability of most exotic species to compete successfully on the arid and infertile sites occupied by vegetation of series S and L. Other factors may also be influential. Streams bordered by gallery forests (types R3 and R4) may bring periodic inputs of seeds from residential areas in their catchments. Types MT2, MT3, R1 and R2 occur along estuarine foreshores where the easy access by water has resulted in considerable human visitor numbers with accompanying disturbance.

TABLE 9

Presence of exotic species[1] in the various quadrat groups

	M1	M2	M3	M4	M5	M6	M7	MT1	MT2	MT3	MT4	MT5	R1	R2	R3	R4
Arum italicum																*
Cassia coluteoides													*	*		
Cinnamomum camphorum								*								
Cirsium vulgare														*		
Erigeron floribundus		*								*			*			
Eupatorium adenophorum †				*									*			*
Eupatorium riparium															*	
Gladiolus sp.															*	
Hypochoeris radicata										*						
Lantana camara										*						
Ligustrum sinense															*	*
Passiflora edulis													*	*		
Rubus vulgaris								*							*	*
Tradescantia albiflora															*	

[1] Since this paper was submitted, a number of name changes have occurred. These appear at the end of the List of indicator species.

Implications for management

The findings reported in this paper have several implications for the management of the Park. The vegetation on the limited area of Wianamatta Shale within the Park has been shown to be distinctive. Few equivalent areas would exist elsewhere in the State's system of national parks and reserves, and it would therefore seem worthwhile to ensure that this particular area is conserved. A similar case can be made for the dolerite area on the West Head peninsula.

There is also an argument for giving special consideration to areas carrying vegetation of the MT and R series. These series have a limited distribution within the Park and appear to be particularly vulnerable to invasion by weeds.

Keys to the floristic types

The usefulness of the proposed classification scheme for future management and scientific studies depends on being able to identify any vegetation types as belonging to the appropriate category.

An indicator species key to the floristic types was produced as a by-product of the ISA classification process and is included as an Appendix 1 to this paper.

Ten indicator species are listed for each dichotomous division. A score is derived from the local abundance of these indicators, the right-hand indicators scoring positively, the left-hand ones negatively. The score is compared with the threshold value specified for the division in order to decide which branch to follow.

Strictly, the key should be applied to objectively sited quadrats of the same form as those used in the present survey. A contribution of four units should be entered for indicator species occurring in the innermost 10 m^2, three for indicators within 50 m^2 and so on. However, we have found that the key gives accurate results when used under less stringent conditions. Under the less stringent procedure, indicators estimated visually to be present at local abundances of greater than one individual per 10 m^2 are allowed four points, with less abundant indicators contributing progressively smaller amounts. For many purposes, this less stringent procedure may be adequate, particularly if verified occasionally by formally keying properly defined quadrats.

Whichever procedure is used, misclassifications will sometimes occur. The outcome should therefore be confirmed by comparing the range of plants actually present with the average profile for the floristic type, as summarized in Table 2.

The vegetation within the Park is similar to that in many nearby undisturbed areas. The question therefore arises as to whether the indicator key could be legitimately applied outside the Park. We feel that the answer is yes, provided that its limitations are clearly recognized. The key contains no provision for dealing with vegetation outside the range of the present classification scheme — any site will key out to one of the 23 types. Only if the site has many species in common with the sites included in the present survey will the result be meaningful. An identification should certainly be checked by referring to Table 2.

There will also be sites within the Park that carry types of vegetation that were not sampled during the survey. However, the inclusion of the set of special-purpose quadrats in the survey greatly extended the range of floristic types that it encompassed and reduced the number of unsampled types. Two examples that are known to remain are the freshwater swamps and the mangrove communities. The key cannot be validly applied to either of those types.

The floristic types as local averages

The analysis identified 23 floristic types differing in floristic, structural and ecological parameters. We do not wish to imply, however, that the Park's vegetation is divided into 23 discrete and isolated categories. On the contrary, the floristic composition of the vegetation seems to be more or less continuously variable. The 23 types are for the most part local averages in a continuum. Thus, there can be variation within the vegetation ascribed to a particular type.

In the event of further data becoming available, it may be possible to subdivide some of the present types. In the interim, it may sometimes be meaningful to describe a site's vegetation as being "of type X but with elements of type Y". We have observed, for example, that some low woodland on a shale-capped ridge bordering Bobbin Head Road keys out as type L1 (low woodland; ridgetops) but has affinities with M1 (moderately low open forest; shale influenced). We suspect that further investigation would show that type L1 could be subdivided in a dichotomy analogous to that which separates M1 to M3 from M4 to M7.

Projected uses of the classification scheme

The potential uses of the classification scheme derive from its properties. It is detailed and hierarchical — differentiation can be to type or series level as the application warrants. The scheme is ecologically meaningful, on both subjective and objective criteria. It can be objectively applied, using the key described in the Appendix.

This last property suits the classification scheme to baseline mapping work, where repeatability between observers is essential. The scheme could also be used for detailed comparisons between areas, as required, for example, in environental impact assessment, evaluation of alternative management regimes, or assessment of an area's conservation status.

CONCLUSIONS

1. Indicator species analysis of the floristic data from 134 quadrats produced 23 distinguishable vegetation types.
2. The dominant axis within the floristic data placed heathland at one extreme, marginal rainforest at the other.
3. The floristically based classification scheme correlated strongly with structural, edaphic and physiographic factors. The most strongly related structural parameter out of those that were recorded was canopy height. The most strongly related physiographic parameter was altitude.
4. The upper divisions in the classification scheme could be well described in structural terms that were more or less consistent with those used by other authors in structurally based classification schemes.
5. The floristic types could be regarded as belonging to five series: S (scrub/heath), L (low woodland), M (moderately low open forest), MT (moderately tall forest) and R (marginal rainforest).
6. The vegetation growing on Wianamatta Shale within the Park constituted a distinct type.
7. The vegetation growing on dolerite constituted a distinct type.

8. The most widely distributed vegetation types were those of the S, L and M series, together covering around 85 per cent of the Park's surface. Marginal rainforest occupied an estimated 2 per cent of the Park's surface.
9. Fourteen species of exotic plants were recorded from survey quadrats. Exotic plants had not invaded scrub and low woodland types (series S and L). They were most abundant in type MT3 and the R series.
10. An indicator species key to the floristic types was found to be reliable in the field.
11. It is suggested that special management effort be directed to areas carrying vegetation of types M3 and those of the MT and R series.

In addition, the following methodological conclusions were drawn:

1. Presence/absence data from 1000 m² quadrats produced a superior classification to that obtained with equivalent data from 50 m² quadrats.
2. The classification scheme was further improved if higher weights were accorded to occurrences near the quadrat centres.
3. In ecological gradients such as occur near stream margins, it appears to be beneficial to record the nearby floristic context provided that the centrally occurring species are given more weight in the subsequent analysis.
4. The floristic range encompassed by the classification scheme was considerably extended through the inclusion of 43 specific purpose quadrats in the survey.

ACKNOWLEDGMENTS

We wish to thank the Director of the New South Wales National Parks and Wildlife Service for permission to carry out the survey and members of the National Parks and Wildlife Service for their assistance. We also wish to thank Mr J.N.R. Jeffers for access to the facilities of the Institute of Terrestrial Ecology (ITE) in England and Dr R. Bunce, M. Shaw and M. Hill of ITE for many helpful discussions about sampling and analysis procedures. We wish to thank R. Buchanan for access to the results of her work of podzols and swamps and Dr D. Adamson for assistance in locating podzol sites. Our thanks are due also to J. Roberts for assisting with data processing.

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APPENDIX 1

Indicator species key to the vegetation types

Ten indicator species are listed for each dichotomous division. A score is derived from the local abundance of these indicators, the right-hand indicators scoring positively, the left-hand ones negatively. The score is compared with the threshold value specified for the division in order to decide which branch to follow. The species abbreviations* are expanded at the end of the key. The interpretive comments are included merely as a guide; the key itself is based solely on floristic characters.

```
1.  Ku-ring-gai_Chase_vegetation
    -ve: Acti mino  Cyat dian  Damp stri  Dill reto          <= -8 ............ 2
         Euca gumm  Lamb form  Lept atte  Phyl phyl          >= -7 ............ 4
         Plat line  Xant medi

2.  Heath, woodland or moderately low open forest
    -ve: Acti mino  Bank aspl  Bank eric | +ve: Ango cost   <= -7 ............ 3
         Hake tere  Hibb cist  Kunz capi |      Pter escu   >= -6 Series M... 10
         Leuc micr                       |      Xant pilo

3.  Heath/scrub or low woodland with dense shrub layer
    -ve: Ango hisp  Darw fasc | +ve: Boss hete  Cono long   <= -3 Series S.... 5
         Epac micr  Grev spec |      Hibb brac  Phyl thym   >= -2 Series L.... 8
         Kunz capi  Styl line |

4.  Medium or moderately tall forest
    -ve: Loma grac | +ve: Acme smit  Blec cart  Call serr   <=  6 Series MT.. 17
         Pter escu |      Cera apet  Hyme cupr  Loma myri   >=  7 Series R... 21
                   |      Smil glyc  Tris laur
-----------------------------------------------------------------------------

5.  Series_S: heath/scrub with or without emergent low trees
    -ve: Damp stri  Dill flor | +ve: Casu dist  Caus pent   <= -1 ............ 6
         Epac obtu  Hake dact |      Erio aust  Phyl phyl   >=  0 ............ 7
         Petr pulc            |      Scho imbe

6.  Not well drained
    -ve: Baue rubi | +ve: Boro pinn  Dill reto  Epac pulc   <=  2 ........... S1
         Epac obtu |      Euca gumm  Loma glau  Loma obli   >=  3 ........... S2
         Lept squa |      Phyl phyl

7.  Rocky, well drained
    -ve: Ango hisp  Baec dios  Bank aspl | +ve: Acac suav   <= -3 ........... S3
         Boro ledi  Hake tere  Hibb cist |      Mirb rubi   >= -2 ........... S4
         Styl line                       |      Pheb squa
-----------------------------------------------------------------------------
8.  Series_L: low woodland
    -ve: Loma glau | +ve: Acac term  Baue rubi  Caus flex   <=  7 ............ 9
         Tetr eric |      Gahn sp.   Halo teuc  Lept squa   >=  8 ........... L3
                   |      Hake tere  Micr eric

9.  Dry, on or near ridges
    -ve: Ango hisp  Bank aspl | +ve: Acac ulic  Erio aust   <= -4 ........... L1
         Boro pinn  Gomp gran |      Euca umbr  Hibb line   >= -3 ........... L2
         Hake dact  Hake gibb |
-----------------------------------------------------------------------------
```

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* Since this paper was submitted, a number of name changes have occurred. These appear at the end of the List of indicator species.

```
10. Series_M: moderately low open forest
    -ve: Acac myrt  Cono long | +ve: Acac term  Styl gram    <= -3 ........... 11
         Cyat dian  Micr eric |      Wool pung  Xant arbo    >= -2 ........... 14
         Pate seri  Phyl thym |

11. Shale and shale related or drier
    -ve: Acti mino  Boro ledi  Boss hete | +ve: Acac myrt    <= -4 ........... 12
         Dill reto  Grev seri  Halo teuc |      Boss obco    >= -3 ........... 13
         Lept atte  Lepy scar            |

12. Not on Wianamatta shale
    -ve: Acac lini  Acac suav  Acti mino  Boro pinn          <= -6 ........... M1
         Dill reto  Halo teuc  Lept flav  Loma long          >= -5 ........... M2
         Tetr eric  Xant trid

13. Usually on Wianamatta shale
    -ve: Anis aven | +ve: Acac myrt  Boro pinn  Boss obco    <=  3 ........... M2
         Lepi late |      Cyat dian  Hibb brac  Micr eric    >=  4 ........... M3
                   |      Pate seri  Pers levi

14. Sheltered sandstone hillsides
    -ve: Dill flor  Erio aust | +ve: Bill scan  Crow sali    <=  1 ........... 15
         Leuc eric  Loma glau |      Dian caer  Grev seri    >=  2 ........... 16
                              |      Smil glyc  Xant trid

15. Upper slopes
    -ve: Phyl phyl | +ve: Boro ledi  Cass pube  Caus flex    <=  6 ........... M4
                   |      Ento stri  Euca pipe  Hake gibb    >=  7 ........... M5
                   |      Lepy scar  Pate seri  Styp tubi

16. Lower slopes
    -ve: Boro ledi  Cono long  Damp stri | +ve: Dodo triq    <= -3 ........... M6
         Epac pulc  Grev seri  Lepy scar |      Lepi late    >= -2 ........... M7
         Petr pulc                       |      Plat lanc
--------------------------------------------------------------------------------

17. Series_MT: medium or moderately tall sclerophyll forest
    -ve: Anis aven | +ve: Eust lati  Glyc clan  Hibb dent    <=  6 ........... 18
                   |      Hydr acut  Impe cyli  Opli aemu    >=  7 ........... 19
                   |      Prat purp  Syno glan  Viol hede

18. On sandstone slopes
    -ve: Acac term  Anis aven  Bank spin | +ve: Astr floc    <= -4 .......... MT1
         Caus flex  Ento stri  Euca umbr |      Casu toru    >= -3 .......... MT2
         Loma sila  Pult daph            |

19. On dolerite or lower slopes
    -ve: Casu toru | +ve: Acac flor  Clem glyc  Euca pilu    <=  2 .......... MT3
         Loma long |      Macr comm  Sync glom  Syno glan    >=  3 ........... 20
         Them aust |      Viol hede

20. Wet sclerophyll with +- closed fern layer
    -ve: Clem glyc  Come volu  Ento stri | +ve: Culc dubi    <= -4 .......... MT4
         Loma sila  Loma grac  Macr comm |      Loma long    >= -3 .......... MT5
         Pate seri  Pros dent            |
--------------------------------------------------------------------------------

21. Series_R: marginal rainforest
    -ve: Astr floc  Ciss hypo | +ve: Aust tenu  Call serr    <= -1 ........... 22
         Eust lati  Pter escu |      Hyme cupr  Loma myri    >=  0 ........... 23
         Sche undu            |      Tris laur
```

```
22. Sheltered slopes
    -ve: Astr floc  Ciss hypo ¦ +ve: Gloc ferd  Gram bill    <=  0 ........... R1
         Hibb dent  Lepi elat ¦      Hyme cupr  Mori jasm    >=  1 ........... R2
                              ¦      Stic flab  Tode barb

23. Stream-side gallery forest
    -ve: Acme smit  Blec cart ¦ +ve: Aust tenu  Ento stri    <=  0 ........... R3
         Eupa ripa  Ligu sine ¦      Gram bill  Loma myri    >=  1 ........... R4
                              ¦      Pheb dent  Tris laur
```

List of indicator species

Acacia floribunda
Acacia linifolia
Acacia myrtifolia
Acacia suaveolens
Acacia terminalis
Acacia ulicifolia
Acmena smithii
Actinotus minor
Angophora hispida
Angophora costata
Anisopogon avenaceus
Astrotricha floccosa
Austromyrtus tenuifolia

Baeckia diosmifolia
Banksia aspleniifolia
Banksia ericifolia
Banksia spinulosa
Bauera rubioides
Billardiera scandens
Blechnum cartilagineum
Boronia ledifolia
Boronia pinnata
Bossiaea heterophylla
Bossiaea obcordata

Callicoma serratifolia
Cassytha pubescens
Casuarina distyla
Casuarina torulosa
Caustis flexuosa
Caustis pentandra
Ceratopetalum apetalum
Cissus hypoglauca
Clematis glycinoides
Comesperma volubile
Conospermum longifolium
Crowea saligna
Culcita dubia
Cyathochaeta diandra

Dampiera stricta
Darwinia fascicularis
Dianella caerulea
Dillwynia floribunda
Dillwynia retorta
Dodonaea triquetra

Entolasia stricta
Epacris microphylla
Epacris obtusifolia
Epacris pulchella
Eriostemon australasius
Eucalyptus gummifera
Eucalyptus pilularis
Eucalyptus piperita
Eucalyptus umbra
Eupatorium riparium
Eustrephus latifolius

Gahnia sp.
Glochidion ferdinandi
Glycine clandestina
Gompholobium grandiflorum
Grammitis billardieri
Grevillea sericea
Grevillea speciosa

Hakea dactyloides
Hakea gibbosa
Hakea teretifolia
Haloragis teucrioides
Hibbertia bracteata
Hibbertia cistiflora
Hibbertia dentata
Hibbertia linearis

Hydrocotyle acutiloba
Hymenophyllum cupressiforme

Imperata cylindrica

Kunzea capitata

Lambertia formosa
Lepidosperma elatius
Lepidosperma laterale
Leptospermum attenuatum
Leptospermum flavescens
Leptospermum squarrosum
Lepyrodia scariosa
Leucopogon ericoides
Leucopogon microphyllus
Ligustrum sinense
Lomandra glauca
Lomandra gracilis
Lomandra longifolia
Lomandra obliqua
Lomatia myricoides
Lomatia silaifolia

Macrozamia communis
Micrantheum ericoides
Mirbelia rubiifolia
Morinda jasminoides

Oplismenus aemulus

Patersonia sericea
Persoonia levis
Petrophile pulchella
Phebalium dentatum
Phyllanthus thymoides
Phyllota phylicoides
Platysace lanceolata
Platysace linearifolia
Pratia purpurascens
Prostanthera denticulata
Pteridium esculentum
Pultenaea daphnoides

Schelhammera undulata
Schoenus imberbis
Smilax glycinoides
Sticherus flabellatus
Stylidium graminifolium
Stylidium lineare
Styphelia tubiflora
Syncarpia glomulifera
Synoum glandulosum

Tetratheca ericifolia
Themeda australis
Todea barbara
Tristania laurina

Viola hederacea

Woollsia pungens

Xanthorrhoea arborea
Xanthorrhoea media
Xanthosia pilosa
Xanthosia tridentata

Name changes

Since this paper was submitted, a number of name changes have occurred. These are: *Eupatorium adenophorum* to *Ageratina adenophora; Eupatorium riparium* to *Ageratina riparia; Haloragis teucrioides* to *Gonocarpus teucrioides; Hydrocotyle acutiloba* to *H. peduncularis; Smilax glycinoides* to *S. glyciphylla; Stylidium graminifolium* to *S. productum.*

Cunninghamia 1(3), 339–349 (1985)

MATURATION PERIODS FOR FIRE-SENSITIVE SHRUB SPECIES IN HAWKESBURY SANDSTONE VEGETATION

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(Accepted for publication 11.5.1984)

ABSTRACT

Benson, D. H. (National Herbarium of New South Wales, Royal Botanic Gardens, Sydney, New South Wales, Australia 2000) 1985. Maturation periods for fire-sensitive shrub species in Hawkesbury Sandstone vegetation. Cunninghamia 1(3), 339–349. The maturation times (period from germination to flowering) for a number of fire-sensitive shrub species in Hawkesbury Sandstone vegetation at sites in Brisbane Water National Park and at Glenorie near Sydney were recorded from marked seedlings established after hot fires. They range from two to seven years for different species. The implications for fire management, particularly for controlled burning, are discussed. A fire-free period of at least nine to ten years is recommended for similar vegetation if successful flowering and seed set, and continued species survival is to occur.

INTRODUCTION

Plant species fall into two main groups with regard to their response to fire: some are characterized by vegetative regrowth, where individuals either resprout from epicormic shoots on the trunk and major surviving limbs or, following the death of all above-ground stems, resprout from underground rootstocks, lignotubers or rhizomes (sprouters); others regenerate from seed either stored in the soil before the fire, carried on the plants in woody fruits and released after the fire, or carried in from adjacent unburnt areas (non-sprouters). Adults in the second group are fire-sensitive and generally killed outright (Gill, 1975, 1981; Bradstock, 1981).

The relative proportions of these groups of species appear to be related to the fire frequency in the habitat (Christensen, Recher & Hoare, 1981). In wet sclerophyll forest the proportion of fire-sensitive species is roughly 50 to 60 per cent (Ashton, 1981). In the more frequently burnt dry sclerophyll forests near Canberra, Purdie & Slatyer (1976) found 65 per cent regenerated vegetatively but only 27 per cent of species were fire-sensitive and only regenerated from seed.

The time necessary for reproduction after fire is an important characteristic, especially in fire-sensitive species. Specht, Rayson & Jackman (1958) noted that fires at intervals of five years in heath vegetation are likely to eliminate or reduce numbers of some species that take several years to reach reproductive maturity. Similarly, for bushland north of Sydney, Siddiqi, Carolin & Myerscough (1976) recorded the localized elimination of the woody fire-sensitive species *Banksia ericifolia*, *Allocasuarina distyla* and *Hakea teretifolia* by repeated burning. However, to predict the impact of a series of fires, data on the maturation periods for fire-sensitive species are needed. With some exceptions, e.g. *Banksia ericifolia* (Carpenter & Recher, 1979) and *Leptospermum laevigatum* (Burrell, 1968), such data are not available. The potential effect of frequent burning on fire-sensitive species has become particularly relevant with the increased adoption of "controlled" or "prescribed" burning in bushland areas. Such burning generally involves the application of regular fires of low intensity, commonly at intervals of between two and five years.

This paper documents the time required for a group of fire-sensitive species to reach maturity and discusses the implications for regular, frequent burning programs.

METHODS

The main study locality was in Brisbane Water National Park (33° 30′S, 151° 15′E), 40 km north of Sydney. Bushland here is eucalypt-dominated scleromorphic vegetation on low-nutrient Hawkesbury Sandstone. Rainfall is about 1250 mm per annum (Bureau of Meteorology, 1979). The general vegetation is described by Benson & Fallding (1981). A second locality was studied at Glenorie (33° 35′S, 151° 00′E), 15 km north-west of Hornsby, on similar Hawkesbury Sandstone, but with average rainfall of 930 mm per annum, to see whether similar results were obtained in a lower rainfall.

A hot summer (1974–75) fire occurred at the Brisbane Water locality six months before the first observations were made and the size of dead bushes at the time indicated that the area had been unburnt for about 15 years before this. As a result of topographic and drainage features, there was considerable variation in microhabitat; therefore, four sites in generally similar, but slightly different, vegetation were chosen as follows:

- Site A — low-woodland with *Eucalyptus haemastoma* and *E. gummifera* on a gently sloping hillside
- Site B — open-heath on a broad rocky ledge
- Site C — low open-forest of *Banksia serrata* and *Eucalyptus gummifera*
- Site D — woodland of *Eucalyptus piperita* subsp. *piperita* and *E. gummifera* on a sandy ledge below a small cliff-line.

A shrubby understorey characterized all the sites, although site C also had a considerable amount of grassy growth. Sites A and B were poorly drained. All sites were within about 0.5 km of each other.

The Glenorie site was in woodland of *Eucalyptus eximia* and *E. gummifera* on a dry ridgetop and had been burnt in January 1975.

At each site a transect of 10 contiguous 1 m × 1 m plots was established. Each of these plots was subdivided into four 0.5 m × 0.5 m sub-plots and two seedlings within each sub-plot were selected and marked with coloured wires. Seedlings were distinguished from plants regenerating from rootstocks or rhizomes by the presence of cotyledons or by comparison with similar plants that had been dug up and their roots examined. Although restricted to dicotyledonous species, as wide a range of species as possible was chosen, and the most healthy seedlings marked. Table 1 lists the 37 species included in this study, their susceptibility to fire and the total number of seedlings marked ("?" indicates species that are probably fire-sensitive). Initially, 320 seedlings were marked. Many of these died during the first years of recording. Additional plants were marked to replace dead plants during the first two years, after which no additional plants were marked. The occurrence of flowering was recorded four times a year (at Brisbane Water in early March, June, September and December; at Glenorie in early February, May, August and November) for the following eight years.

At the same time all species flowering within about 30 m of the transect were recorded. Because of the range of microhabitats, such as minor cliff-lines, rock platforms and moist soaks, some of which remained unburnt during the fire, flowering recordings may represent as few as one or two individuals of a species.

In July–August 1980 a low-intensity fire burnt part of the Brisbane Water area, including half of the site A transect. There was no canopy scorch and the fire was of such low intensity that in places it was stopped by the trampled single-file track along the edge of the transect resulting from the three-monthly recordings. Although it reduced the amount of data from this site, a number of observations were made on species affected by the fire.

TABLE 1

Susceptibility to fire and number of seedlings recorded for species at Brisbane Water and Glenorie

Botanical name	Susceptibility to fire fs = fire-sensitive r = resprouter	Total number of seedlings marked
APIACEAE		
Actinotus helianthi	fs	44
A. minor	r	6
Platysace linearifolia	r	32
Xanthosia tridentata	?fs	5
DILLENIACEAE		
Hibbertia cistiflora	?fs	5
H. monogyna	?fs	4
EPACRIDACEAE		
Epacris pulchella	fs	2
Leucopogon microphyllus	?fs	5
Woollsia pungens	fs	13
EUPHORBIACEAE		
Poranthera ericifolia	fs	7
FABACEAE		
Acacia hispida	?fs	2
A. suaveolens	fs	4
Bossiaea heterophylla	fs	2
Dillwynia retorta	fs	8
Gompholobium grandiflorum	?fs	6
GOODENIACEAE		
Goodenia bellidifolia	?fs	2
HALORAGACEAE		
Gonocarpus teucrioides	fs	43
LAMIACEAE		
Hemigenia purpurea	?fs	3
LOGANIACEAE		
Mitrasacme polymorpha	fs	6
PROTEACEAE		
Banksia ericifolia	fs	22
B. oblongifolia	r	7
B. serrata	r	3
Conospermum taxifolium	fs	2
Grevillea buxifolia	?fs	2
G. sericea	fs	18
G. speciosa	?fs	2
Hakea teretifolia	fs	15
Petrophile pulchella	fs*	26
RHAMNACEAE		
Cryptandra ericoides	?fs	3
RUTACEAE		
Boronia ledifolia	fs	12
B. serrulata	fs	1
Eriostemon australasius	fs	3
E. buxifolius	fs	38
Philotheca salsolifolia	fs	2
THYMELAEACEAE		
Pimelea linifolia	fs	4
TREMANDRACEAE		
Tetratheca ericifolia	?fs	8
T. shiressii	?fs	4

* Beadle (1940) states that *Petrophile pulchella* has a lignotuber and 92 per cent survival after fire. This is not the case at the study sites here or elsewhere in the Sydney district according to the author's general observations.

RESULTS

The number of years to first flowering of marked seedlings is shown in Table 2. The time taken for different species ranges from one year for *Poranthera microphylla* to seven to eight years for *Banksia ericifolia,* with many species taking four to six years. Although different species are present, the pattern at each site was similar. Table 3 shows the pattern of flowering at site D for the eight-year period. The first flowering for several species took place within two years of the fire, followed by the gradual addition of other species during the succeeding five years. A similar pattern was recorded for the other three sites at Brisbane Water and that at Glenorie.

The onset of flowering rarely included all individuals of a population and commonly only involved a few particularly advanced plants. Figure 1 shows the actual numbers of marked plants for selected species at site D at Brisbane Water and at Glenorie. Here, on the first flowering occasion, between 10 and 40 per cent of individuals of a species were involved, but flowering did not reach a peak for another one to several years. Similar results were obtained for species at the other sites.

TABLE 2

The number of years to first flowering after fire for shrub species at Brisbane Water and Glenorie. Species are arranged in increasing maturation time

Botanical name	Brisbane Water sites				Vicinity	Glenorie site	Vicinity
	A	B	C	D			
Poranthera ericifolia	1				1		
Hemigenia purpurea		2			2		
Actinotus helianthi				*2(3)	1	2(4)	2
A. minor	2			3	1		
Mitrasacme polymorpha	3	2		2	1		
Gonocarpus teucrioides	2		4		2		
Bossiaea heterophylla				3	2		
Cryptandra ericoides		3			3		
Hibbertia cistiflora		3			1		
Tetratheca ericifolia	3			3	1		
T. shiressii	3	4			3		
Platysace linearifolia	3			3(4)	2	3(4)	3
Woollsia pungens				3(5)	2		
Conospermum taxifolium		4			1		
Eriostemon australasius				4	1		
Goodenia bellidifolia				4	1		
Grevillea speciosa		4			1		
Hibbertia monogyna		4			2		
Pimelea linifolia			4		1		
Boronia ledifolia	4			5	1		
Leucopogon microphyllus	4	5			2		
Gompholobium grandiflorum	4			6	4		
Grevillea sericea	4		4(6)		3		
Eriostemon buxifolius			5(5)	5	1	4(6)	4
Acacia suaveolens				5	2	4	4
Boronia serrulata				5	1		
Dillwynia retorta		5			1		
Philotheca salsolifolia		5			2		
Acacia hispida						5	3
Xanthosia tridentata			6		1		
Epacris pulchella		6			4		
Hakea teretifolia	6	6(6)		7	2		
Petrophile pulchella		6		9	2	8(9)	5
Banksia ericifolia	8	8		7	2		
Grevillea buxifolia						8	6
Banksia oblongifolia	no flowering yet						
B. serrata	no flowering yet						

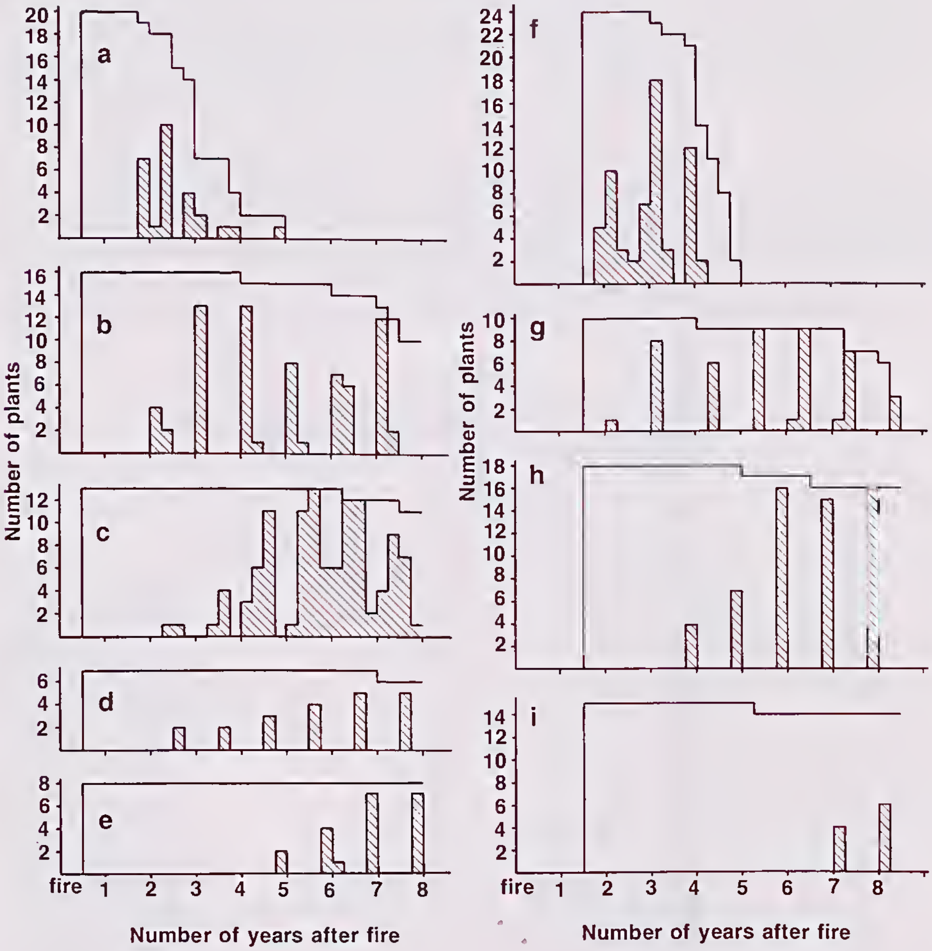
* Where 10 or more individuals of a species were marked at one site, the number of years taken to reach at least 50 per cent of individuals flowering is given in brackets.

TABLE 3

Flowering times for marked plants at Brisbane Water National Park (site D). Months (M J S D) of recording were March, June, September, December

Botanical name	Fire												Time since fire (years)															
	2				3				4				5				6				7				8			
	M	J	S	D	M	J	S	D	M	J	S	D	M	J	S	D	M	J	S	D	M	J	S	D	M	J	S	D
Mitrasacme polymorpha			x	x	x	x						x																
Actinotus helianthi				x	x	x		x	x		x	x				x												
Platysace linearifolia					x	x			x				x	x			x	x			x	x			x	x		
Woollsia pungens						x	x			x	x		x	x	x		x	x	x	x	x	x	x	x	x	x	x	x
Actinotus minor						x			x			x	x			x				x	x			x	x			x
Boronia ledifolia							x				x				x				x				x				x	
Bossiaea heterophylla							x			x						x						x				x		
Tetratheca ericifolia								x	x			x			x	x			x	x			x	x	x	x	x	x
Eriostemon australasius											x				x	x			x				x				x	
Goodenia bellidifolia												x																
Hibbertia monogyna													x			x	x	x	x	x	x		x	x	x	x	x	x
Acacia suaveolens														x				x				x				x		
Boronia serrulata															x				x				x	x	x			
Eriostemon buxifolius																x				x	x			x				x
Gompholobium grandiflorum																			x					x			x	
Banksia ericifolia																					x					x		
Hakea teretifolia																					x							

Figure 1. Flowering periods after fire for selected species at Brisbane Water (site D) (a–e) and Glenorie (f–i), showing total marked seedlings (upper line) and number flowering (hatched bar) for *Actinotus helianthi* (a & f), *Platysace linearifolia* (b & g), *Woollsia pungens* (c), *Boronia ledifolia* (d), *Eriostemon buxifolius* (e & h) and *Petrophile pulchella* (i). For each graph, the vertical axis represents number of plants, and the horizontal axis represents number of years after fire.



Fruit set occurred in most species. An exception was *Grevillea sericea* in which marked plants failed to set fruit after first flowering, but did so after subsequent flowering. In many species, notably those of the family Rutaceae, seed is released within a few months of flowering, but some species, particularly those of the woody-fruited Proteaceae, take a year after flowering for the characteristic woody follicles to develop. Examples are *Banksia ericifolia, Hakea teretifolia* and *Petrophile pulchella,* the slowest to flower of the species in the study area.

A decline in numbers following flowering was recorded for *Mitrasacme polymorpha, Poranthera ericifolia* and in particular *Actinotus helianthi.* Individuals of these species had completely disappeared within five years; they may be regarded as early successional species. No further species disappeared from the plots during the recording period except for a number of species represented by only a single marked individual.

The recorded times to achieve flowering for plants in the vicinity (Table 2) are almost all much shorter than for the marked plants, but do not really indicate the responses of the population as a whole. This is because many recordings are of individuals that were either unaffected or only slightly affected by the fire, as a result of the protection offered by the minor cliff-line, rock-outcrop and moist-soak microhabitats. The results indicate the potential resilience of a system in which considerable topographic variation provides fire refugia, but cannot be extrapolated to sites with less variable topography.

The effect of the low intensity fire at site A was interesting — *Poranthera ericifolia* and *Gonocarpus teucrioides,* which had died out before the fire, reappeared. However, individuals of *Platysace linearifolia,* which had appeared only as seedlings after the 1974–75 summer fire, were not killed but resprouted at ground level, indicating that fire-sensitivity in that species may be related to the intensity of the fire.

DISCUSSION

Fire-sensitive species may make up a significant component of Australian vegetation. For example, in dry sclerophyll communities near Canberra, of 93 species studied by Purdie & Slatyer (1976), 27 per cent were killed by fire and regenerated only from seed. A similar proportion are present in the scleromorphic flora of Sydney's Hawkesbury Sandstone, particularly on the higher rainfall coastal areas. Of the species recorded in this study 20 are known to be fire-sensitive, and a further 13 are probably so. The only resprouter species to be marked were *Actinotus minor, Platysace linearifolia, Banksia oblongifolia* and *B. serrata* (neither of the marked *Banksia* species flowered during the recording period). Fire-sensitive species are likely to be severely disadvantaged and possibly eliminated by a series of fires at intervals less than the time taken for seedling regeneration to produce further seed. The results here show that fire-sensitive species may not flower for two to eight years after a fire. Major flowering is not attained for one or two years after that. Similar results were found for all sites at Brisbane Water and also at Glenorie, and are likely to apply to other areas on Sydney's Hawkesbury Sandstone.

The results highlight the variability present within most wild populations. For instance, although most individuals may flower simultaneously, there will generally be some individuals flowering out of season.

Flowering is an effective indicator of maturity only if it is associated with the development of mature viable seed and leads to the build-up of an adequate seedbank. Some species, particularly those with woody fruits, take up to a year for the fruits to mature, and are vulnerable to fire during this period. Examples are *Banksia ericifolia, Hakea teretifolia* and *Petrophile pulchella.* Although fruit formation generally appears to accompany flowering, the percentage viability of the first seeds set by an individual may not be known. In *B. ericifolia, B. serrata, P. pulchella* and *Isopogon anemonifolius,* first seed set on juvenile plants is normal in terms of viability, i.e. it is comparable to seed viability produced in older plants. However, the number of seeds per cone is often significantly lower in the first and second crops (R. Bradstock, pers. comm.). The density of seedlings at the beginning of this work and the early seedling mortality encountered suggest that some species recruit from a relatively large seedbank either already stored in the soil or available from woody capsules. Certainly, for the survival of each species a minimum seedbank must be present, though the necessary size for most species is unknown.

Without this seedbank, floristic composition will change to a dominance by resprouter or rhizomatous species, or to annual species, commonly exotics, which seed rapidly. Though rhizomatous species such as *Pteridium esculentum* and monocotyledonous families such as Poaceae and Cyperaceae can spread vegetatively, most dicotyledonous resprouters, with the exception of some which root-sucker, cannot and so rely on seed for the establishment of new individuals. Frequent burning may possibly weaken and eventually kill individual resprouters, so that some seedling establishment is necessary to replace them if the plant community composition is to remain reasonably stable. The critical fire-free period here will be the interval from seedling establishment to the production of an adequate fire-resistant rootstock. However, since seedling recruitment will not be necessary after every fire, the critical fire-free period will not be needed for every fire cycle.

Almost all seedlings appear to establish in the first two years after fire, when there is considerable seedling mortality. Similar results were recorded by Purdie (1977) for dry sclerophyll vegetation near Canberra. After this period, with the exception of a few short-lived species (e.g. *Actinotus helianthi*), few of the marked plants died, despite very dry conditions during the latter part of the recording period. Eight years after fire the shrub component of the plant community appears healthy and actively growing, with no sign of senescence. It is likely that such conditions will continue for 15 to 20 years after fire.

The localized elimination of the tall woody species *Banksia ericifolia, Allocasuarina distyla* and *Hakea teretifolia* by frequent repeated burning has been reported at North Head, Sydney (Siddiqi *et al.,* 1976). Generally, however, the local disappearance of species in bushland has not been recorded. If there has indeed been a loss, the absence of observations could be for two reasons.

Firstly, the physiographic and habitat variation within the Hawkesbury Sandstone environment provides an uneven burn pattern with varying local fire intensities and localized fire refuges such as around rocky outcrops, cliff-lines or moist gullies. Our records of flowering within a year of the 1974–75 fire by the fire-sensitive species *Boronia serrulata, Eriostemon buxifolius* and *E. australasius* were from unburnt individuals growing amongst rock outcrops, which had provided fire protection. Thus, a plant community may be able to recover from potentially disastrous too-frequent burns by re-invasion from unburnt refuges. However, a succession of frequent burns will greatly increase the chances of losing species.

Secondly, the impressive species richness and diversity of plant communities on Hawkesbury Sandstone (426 dicotyledons are recorded for Brisbane Water National Park by Benson & Fallding, 1981) obscures, for most casual observers, changes in the abundance of individual species, particularly the less abundant and less conspicuous species, and particularly where such changes may be taking place gradually over decades. Most of the literature on the effect of fires on fire-sensitive species in the Sydney area concerns *Banksia ericifolia,* one of the most conspicuous and abundant species (e.g. Carpenter & Recher, 1979; Bradstock & Myerscough, 1981). Indeed, it may be the less common species that are more likely to be endangered by too-frequent fires. In their list of rare and restricted species in Brisbane Water National Park, Benson & Fallding (1981) include a number that are probably fire-sensitive. These include *Leucopogon amplexicaulis,* found in areas with low fire frequency, *L. margarodes* in areas not burnt for eight to ten years, *Darwinia procera* on a rocky ridge, and *D. glaucophylla* on rock outcrops that evidently protect it from fire, but it is not known whether these have previously been more abundant and whether frequent burning has endangered them.

FIRE MANAGEMENT IN NATURAL AREAS

The effects of frequent burning in bushland areas have become particularly important with the increasing use of regular burning as a management tool. Such burning may be "controlled" (and intended only for fuel reduction) or "prescribed" (and sometimes involve biological as well as fuel reduction aims). Both involve the application of regular low-intensity fires, generally at intervals of between two and five years, though planned frequencies often vary widely in reality, to reduce flammable fuel. This is most commonly carried out during cool weather in autumn or spring, in order to keep fire intensities low and manageable. High-intensity prescribed burning is theoretically possible and may be biologically desirable, but there are problems with implementation (for details see Good, 1981; Luke & McArthur, 1978; Foster, 1976).

The use of control burning at these frequencies may have the following deleterious effects, which will be particularly undesirable in areas reserved for the protection of native plants.

(1) Fire-sensitive species may be eliminated by repeated burning at time intervals that are less than that required to produce seed. For example, burning an area several times in quick succession is reported by Luke & McArthur (1978) to eliminate species of *Acacia* by exhausting their seedbank without allowing it to be replaced.

(2) Fruiting in both fire-sensitive and fire-resistant species may be reduced by burning when the plants are in flower or have immature fruits. Though there will generally be some species in flower at any time of the year, many species have a concentrated peak in spring (Timms, 1978), followed by seed maturation and release in summer. This is common in the families Fabaceae and Rutaceae, which are particularly conspicuous in the Hawkesbury Sandstone flora. Thus, a season's potential seed supply may be destroyed by burning when it is immature.

(3) Fire-resistant species may be eliminated by continual weakening and death of individuals. For example, Noble (1982) reports that in western New South Wales, mallee eucalypts, generally regarded as having a marked tolerance to periodic fire through their ability to produce epicormic shoots, do die when burnt more than once, especially when one burn closely follows another.

(4) Low-intensity fires may not stimulate adequate seedling germination, though allowing rhizomatous regeneration. Gill (1975) noted that for the Australian flora a high burning frequency often leads to dominance by monocotyledonous and fern species in place of shrubs. For example, Bradley (1972) reports on the occurrence of *Pteridium esculentum* and *Culcita dubia* after cool burns in Sydney bushland, while Luke & McArthur (1978) refer to *Imperata cylindrica* as prominent in coastal forests of northern New South Wales that have been burnt extensively.

A likely result of these factors is that areas of bush may be simplified both floristically and structurally.

For the fire-sensitive species examined, a period of six to seven years is needed to reach regular flowering. In addition, another year is required by some of the slowest-flowering species to develop mature seed. The question of the time needed to establish adequate seedbank reserves, either in the soil or within the plant canopy, has not been determined for many species. It is likely that most species require several seed-bearing seasons for this. Thus, for the communities examined a minimum fire-free period of nine to ten years is needed in a majority of fire cycles. An occasional burn followed quickly by another may be tolerated as seed reserves in the soil may not necessarily be exhausted by one fire. However, this is dependent on an adequate seedbank having been built up prior to the first fire.

The implications for fire management in natural areas are obvious. Before a long-term burning regime is imposed on an area of native bushland, the consequences of that action should be evaluated. As far as the survival of plant species is concerned, where there are often very little reliable data, it is necessary to err on the conservative side. That is, the time intervals between burns, in a majority of fire cycles, should be longer than the minimum suggested by the present findings.

ACKNOWLEDGMENTS

This paper would not have been possible but for the enthusiasm and dedication of Dorothy Darvodelsky, Avril Donovan, Florence Dwight, Marie and John Glass, Marge Gowan, Valerie Jones, Clarice Morris and Peter Price, who germinated interest in the work and have continued with the data collection every three months, in all weathers. The assistance of staff from the Hawkesbury District Office of the National Parks and Wildlife Service is gratefully acknowledged. I would also like to thank Ross Bradstock, Jocelyn Powell, Marilyn Fox, Heidi Fallding and David Keith for commenting on the manuscript.

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Cunninghamia 1(3), 351–369 (1985)

VEGETATION OF THE MERRIWA AREA, NEW SOUTH WALES

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(Accepted for publication 15.12.1983)

ABSTRACT

McRae, R.H.D. & Cooper, M.G. (National Herbarium of New South Wales, Royal Botanic Gardens, Sydney, New South Wales, Australia 2000) 1985. Vegetation of the Merriwa area, New South Wales. Cunninghamia 1(3), 351–369. The vegetation of the Merriwa area (covered by the Merriwa 1:100 000 map sheet, and bounded by latitudes 32° 00′ and 32° 30′S and longitudes 150° 00′ and 150° 30′E) lies in the botanical subdivision of the Central Western Slopes but has affinities with the vegetation of five others. Inland elments of the flora co-exist here with those normally associated with the Coast or the Tablelands. The plant communities strongly reflect the dry climate and the geology — different groups of communities were recognized on soils derived from basalt, sandstones and alluvium. Several communities and a number of species are restricted to the area. Traditional land use has involved the clearing of the basalt plains and river flats for cattle and sheep grazing, and the growing of wheat and other crops. Much of the vegetation on the sandstone has remained reasonably undisturbed and large areas have recently been conserved within national parks.

INTRODUCTION

The Merriwa area, covered by the Merriwa 1:100 000 topographic map (sheet no. 8933, Division of National Mapping, 1970), is bounded by latitudes 32° 00′ and 32° 30′S and by longitudes 150° 00′ and 150° 30′E, and covers about 2600 square kilometres. It lies east of the Great Divide, between the highlands at the northern end of the Sydney Basin and the foothills of the Liverpool Range, and includes part of the valley of the Goulburn River, the western branch of the Hunter River (Figure 1). Major towns in or near the area include Bylong, Cassilis, Denman, Merriwa, Sandy Hollow and Ulan (Figure 1).

The flora of the Goulburn River district was first studied by Allan Cunningham who, in the 1820s, collected plant specimens along the edge of the Goulburn River valley. Seventy years later the Sydney botanist R.T. Baker, assisted by a Rylstone surveyor, J. Dawson, collected to the south-west of the Goulburn River (Baker, 1896). Other botanists who have made collecting trips to the area include J.L. Boorman, early this century, and L.A.S. Johnson, in the 1950s. Dorman (1972) prepared a species list for Mt Dangar, "Murrumbo", the Bylong River valley, Lees Pinch and Wollar, all frequently visited sites with road access. Vegetation reports on the conservation potential of the Goulburn River have been prepared by the New South Wales National Parks and Wildlife Service (e.g. Ingram, n.d.). Regional overviews of the vegetation, such as those by Burley (1961), Story (1963), Forster (1981) and the Soil Conservation Service (n.d.), are very generalized and provide little floristic information.

THE STUDY AREA

Climate

The climate is temperate, with mean annual rainfall up to 660 mm, but the lower sandstone areas and the basalt plains are drier, with mean annual rainfall between 500 mm and 600 mm (based on a regional rainfall map in Tweedie, 1963). The distribution of rainfall is strongly influenced by the highlands to the north and

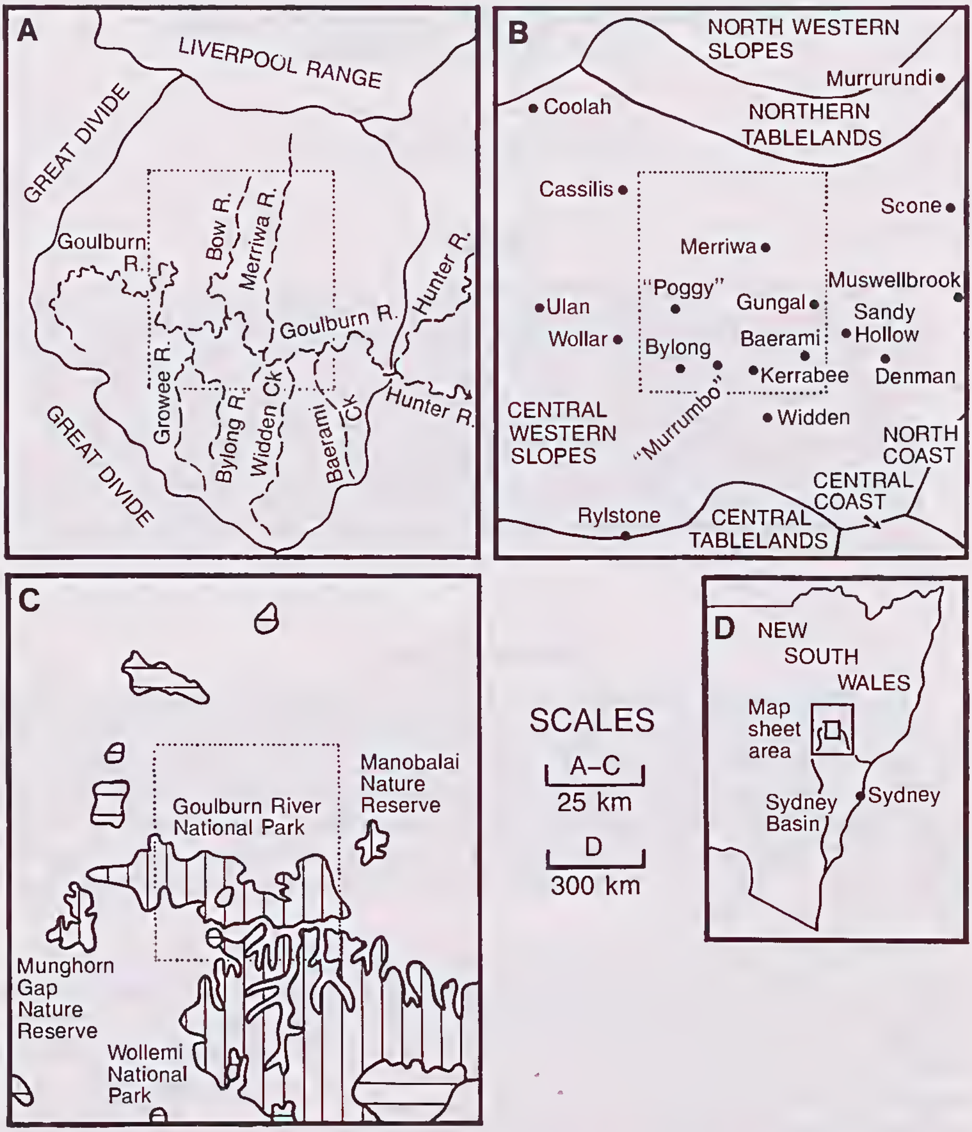

Figure 1. Location map, showing (A) the locations of watersheds and rivers; (B) main towns and botanical subdivisions of the region; (C) location of National Parks, Nature Reserves and State Forests and (D) location of the Merriwa Sheet in the State.

south, which often divert thunderstorms away from the lower areas, and by the lack of a prominent Great Divide. The pattern of monthly rainfall is generally uniform, but with a peak in summer and another lesser peak in winter. The lowest mean monthly rainfall is about 60 per cent of the highest (based on figures for Cassilis in Bureau of Meteorology, 1975).

The mean monthly temperatures are highest in December and January, with 32°C mean monthly maximum and 18°C mean monthly minimum at Sandy Hollow and 30°C mean monthly maximum and 14°C mean monthly minimum at Cassilis (Bureau of Meteorology, 1975). There is little variation in mean temperatures throughout the district, except with distance inland and differences in altitude

(Tweedie, 1963). Humidity is high in the winter months (up to 90 per cent mean monthly relative humidity based on data for Cassilis in Tweedie, 1963) and lower in summer (less than 60 per cent). There are between 18 and 26 weeks of the year with sufficient moisture for unrestricted plant growth (Tweedie, 1963).

Geology

The two main components are the sedimentary series of the northwestern Sydney Basin and the basalt flows of the Liverpool Range (New South Wales Department of Mines, 1969). In the valleys the geology is obscured by alluvium and colluvium.

In the southern half of the area the sedimentary strata are predominantly of the Triassic Narrabeen Group, mainly siltstones and sandstones, with underlying Permian beds of sandstone, siltstone and coal exposed in the deeper valleys. These strata have a local dip of about one degree to the north. Small outliers of the Jurassic Pilliga Sandstone occur near Merriwa.

In the northern half of the area volcanic activity in the Tertiary period covered the sedimentary stata with very deep basalt flows forming the Merriwa Plains and the foothills of the Liverpool Range. A number of volcanic necks are exposed today (e.g. at "Murrumbo", 10 km west of Kerrabee; Stony Pinch, 8 km west of "Murrumbo"; and "Poggy", 25 km south-west of Merriwa). A later series of basaltic flows filled in the entrenched valley of the Goulburn River (Galloway, 1967).

Geomorphology

The geomorphology is largely determined by the extent of the basalt deposits and by the differential erosion rates between the Triassic and Permian sedimentary strata. The Narrabeen Group is fairly resistant to erosion, and forms plateaux and narrow, cliff-lined valleys. At Morrisons Flat (10 km north-east of Bylong) and above its junction with Mt Misery Creek (8 km north of Bylong), the Goulburn River cuts into the softer underlying Permian strata, leading to undercutting of the sandstone cliffs and resulting in pronounced valley widening, with colluvium and talus slopes. Downstream from Drummers Flat (7 km north-west of Kerrabee) the valley is mature, and little talus occurs. South of the river, talus is again absent where the slope of the ridgetops matches the dip of the strata.

The Merriwa Plains are gently undulating, with major valleys about 10 km wide and with local relief of 100 to 150 m. The basalts south of the river have mostly eroded, and since the Tertiary the river beds have dropped about 50 m, with only local changes in course. Through relief reversal, remnant basalt caps are now found on many sandstone spurs overlooking the Goulburn River and most of its tributaries. North of the Goulburn River, most of the streams have cut through the thick basalt flows to expose the underlying Triassic and Jurassic strata.

Soils

The sandstone plateaux have coarse-textured, often skeletal, sandy soils of variable depth, with a clay component where claystones or siltstones have contributed to them. The soils on the steeper sandstone are often composed of colluvium or talus. On the Merriwa Plains there are shallow cracking clays and fine-textured, skeletal sandy soils. The alluvial regosols found in all main valleys are of a variable nature, depending on the local geology (Van de Graaff, 1963). The edges of these deposits are often covered by colluvium derived from weathering of the low sandstone cliffs.

Land use

Woodland or open-woodland communities appear to have been the characteristic vegetation before European settlement. These helped to support a relatively large population of Aborigines, as evidenced by the many art and habitation sites near the river. The effects that these earliest inhabitants had upon the area are unclear, and have been obscured by recent changes. Today, there are a variety of land uses. The alluvial soils support cattle grazing, stud farms and a low intensity of timber cutting. The woodlands on the Merriwa Plains basalt have been largely cleared for cattle and sheep grazing, and the growing of cereal crops. The sandstone ridges are virtually unused for agriculture. Merriwa is the main service town, with facilities for rail transport of grain. The coal railway from Gulgong to Sandy Hollow traverses the area, and the basalt quarries, used for track ballast and for roadworks, are situated near Bylong. The sandstone ridges to the south are included in the Wollemi National Park. Major new land uses include the Goulburn River National Park, new mines being planned for the coal reserves that underlie the plateaux, and a 500 kV power transmission line that will traverse the area from east to south-west.

METHODS

Areas of vegetation with similar structural and floristic characteristics, with associated geological and physiographic characteristics, were recognized using aerial photopatterns (photographs from the Water Resources Commission, Kerrabee Dam Series, 1980, circa 1:15 000 scale and the New South Wales Lands Department, Merriwa Series, 1977, 1:75 000 and 1:53 000 scales) and used to form the map units. These are not all of equivalent rank as a number are made up of several plant communities associated with particular geologic or physiographic types, whereas others are more clearly plant associations (*sensu* Beadle & Costin, 1952). Generally the term "plant community" is used for the basic vegetation unit. Vegetation was classified into structural forms based on the system of Specht (1970).

The central area of the map was examined in the most detail with community habitat, structure and composition being recorded in 20 m × 20 m quadrats at 19 sites. The locations of these sites and the full data, collected between December 1980 and March 1981, and during September 1981, are available from the National Herbarium of New South Wales. Community distribution patterns within the valleys of the Goulburn and Merriwa rivers were studied along transects ranging up to 3 km in length (see map). In other areas, roads and fire trails were traversed and floristic data collected to complement the data from the central section. Appendix 1 lists the species found in the various communities.

VEGETATION

Generally, the vegetation of the area is a woodland dominated by *Eucalyptus* species, particularly species of box, ironbark and red gum. *Callitris* pines are common, as are acacias. Understorey shrubs are generally scarce, but in scattered exposed sites with skeletal soils they become dominant. Ground cover was very sparse throughout the survey period, as a result of drought and grazing. In scattered sheltered sites, usually near cliffs and often with some basalt influence, rainforest shrubs occur, mostly in a stunted form. They are more frequent to the south, east and north, where the rainfall is higher.

The major map units or map unit groups recognized are:

1. open-woodland on basalt
2. woodland on basalt of foothills of Liverpool Range

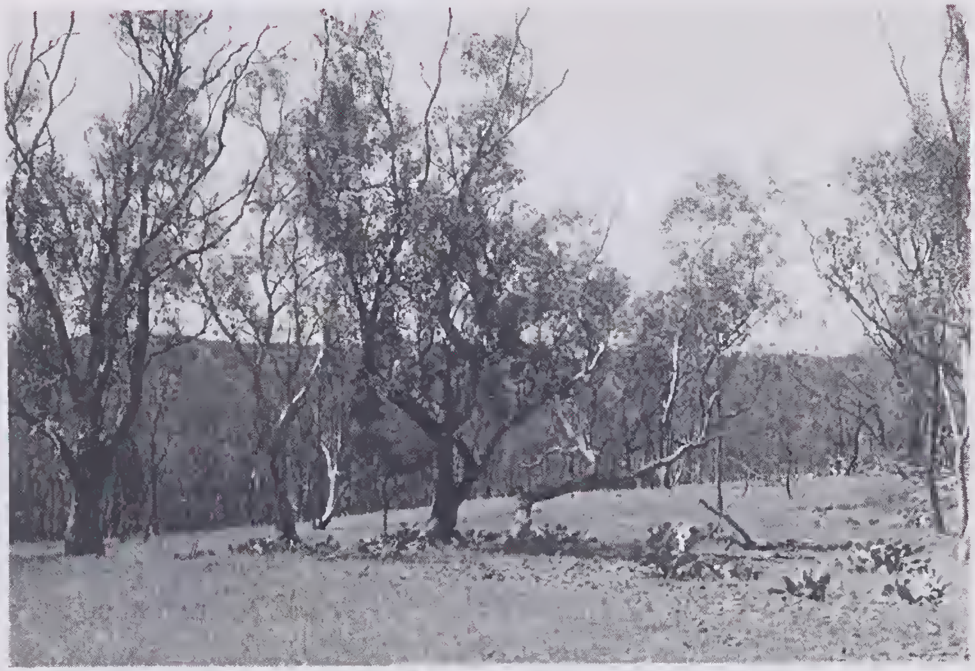

Figure 2. Open-woodland of *Eucalyptus albens–E. moluccana* intergrade (Community 1) on a basalt residual near Morrisons Flat. Note the characteristically open understorey with **Opuntia stricta.*

3. woodland/open-woodland on alluvium
4. woodland in sandstone gullies
5. woodland/low open-woodland/low shrubland on shallow soils on Narrabeen Group
6. woodland/open-woodland/open-scrub on deeper soils on Narrabeen Group.

1. Open-woodland on basalt

This group of map units contains four communities, each physiographically distinct. They occur on the Merriwa Plains, on basalt remnants near the Goulburn River, on remnants towards Nullo Mountain, and on Mt Dangar. All are characterized by widely spaced trees 8 to 15 m high, very little to no shrub cover, and a sparse ground cover consisting mainly of perennial species. The main tree, *Eucalyptus albens–E. molluccana*[†], is an integrade between two related box species, the former species being found commonly to the west, the latter in the Hunter Valley (Figure 2).

An open-woodland of *Eucalyptus albens, E. melliodora* and *Brachychiton populneus* occurs on the Tertiary basalt of the foothills of the Liverpool Range, the Merriwa Plains and also on large isolated basalt residuals, for example at "Poggy", "Mogo" (19 km north-west of Bylong), Stony Pinch and "Murrumbo". The usual landforms are broad valleys and rounded hills with an altitudinal range of from 400 to 500 m above sea level (ASL) and slopes mostly less than 15 degrees. The deep, rocky, basaltic soils, which have largely been cleared for agriculture, support *E. melliodora,* common elsewhere. Other trees present include *E. dealbata* and *E.*

[†] There have been some recent changes in the nomenclature of the eucalypts (L.A.S. Johnson, pers. comm.). The intergrade *Eucalyptus albens–E. moluccana* is called *E.* "albemol"; the intergrade *E. blakelyi–E. tereticornis* is called *E.* "blaketer"; and *E. oblonga* here is to be called *E. sparsifolia.*

moluccana. The understorey is usually affected by grazing or clearing, and **Opuntia stricta* is abundant.

On perched basalt residuals near the Goulburn River is an open-woodland dominated by *Eucalyptus albens–E. moluccana.* These residuals, found between Baerami and Lees Pinch (13 km north of Kerrabee and 13 km north-west of Bylong, respectively), mostly less than 2 km from the river, and at altitudes around 300 m ASL, are situated on the ends of low sandstone ridges, usually 50 to 100 m above the present river bed. Other trees present are *E. albens* s. str. and occasionally *Acacia doratoxylon, A. linearifolia, Allocasuarina*[1] sp. aff. *distyla* and *E. crebra. Notelaea microcarpa* dominates the sparse shrub cover and *Cheilanthes tenuifolia* is common on the rocky ground surface. *Eucalyptus dealbata* is the common eucalypt on the tops, which have slopes less than five degrees and very little soil. *E. albens–E. moluccana* is abundant on the margins on sites that exceed 15 degrees in slope and have deeper soils than the tops. Occasionally all the basalt rock in a residual has weathered and on these sites only *E. moluccana* occurs. In some deeper sandstone gullies, for example at Honeysuckle Creek (near "Murrumbo") and south of Morrisons Flat, small, highly weathered basalt residuals occur, usually on the steep base of a spur. *Eucalyptus moluccana* is found here also.

In the south, in the highlands of the northern portion of Wollemi National Park, are similar residuals associated with the basalt flows of Nullo Mountain. *Eucalyptus albens* is dominant. These residuals have deeper soils and higher altitude than they have elsewhere (around 500 m ASL, and 150 m above the valley floor), and *E. dealbata* and the integrade *E. albens–E. moluccana* do not occur.

Mt Dangar, a conical basalt peak, rising from 400 to 673 m ASL, supports a woodland of *Eucalyptus albens* and *Allocasuarina* sp. aff. *distyla.* The steep slopes (up to 30 degrees) support a shallow rocky soil. Other common species include *Callitris endlicheri, Myoporum montanum* and **Opuntia stricta. Acacia* sp. aff. *decurrens* is endemic to Mt Dangar. There is a narrow band of *E. dawsonii* (see Community 4) at the base of the basalt, possibly indicating an underlying layer of siltstone. The exact geology of the hill is uncertain; the basalt possibly differs from that of the other flows in the valley (Galloway, 1967).

2. Woodland on basalt of foothills of Liverpool Range

At the northern edge of the study area, on the foothills of the Liverpool Range (up to 640 m ASL) is a woodland of straight-trunked trees 15 to 30 m high. The main species are *Eucalyptus melliodora, E. laevopinea, E. viminalis* and *Allocasuarina torulosa,* and occasionally *E. moluccana* and *Brachychiton populneus.* The main shrubs are *Cassinia cunninghamii, Acacia implexa* and *Pittosporum undulatum,* with understorey species including *Indigofera australis* and *Clematis aristata.* This community occurs on deep basaltic soils on slopes up to 40 degrees, usually with a southerly aspect. It represents the southern limit of a major Northern Tablelands alliance, found on the Liverpool and Mount Royal ranges, and on the Great Divide south of Walcha, but is only a minor element of the vegetation of the Merriwa district. Grazing and partial clearing have altered its structure and species composition.

3. Woodland/open-woodland on alluvium

The riparian forests are a distinctive feature of the area. The stands have mostly been modified by selective logging and partial clearing for grazing and, as some stands are regrowth, original densities are difficult to estimate. Shrubs are scarce, and are mainly in rocky situations. The ground cover is often grazed, especially during drought and, after rain, is dominated by fast-growing and short-lived weed species.

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[1] Nomenclature for the Casuarinaceae follows the recent revision of Johnson (1982).

The nature of the parent material has a marked influence on the species composition, and various mixtures of species occur. On alluvium derived mainly from sandstones, the woodland or open-woodland is dominated by *Angophora floribunda*, with other species including *Eucalyptus crebra, Casuarina cunninghamiana* and *Callitris endlicheri* and, less frequently, *Acacia linearifolia, E. blakelyi* and *E. melliodora*. Infrequent species are *E. camaldulensis, E. trachyphloia, Allocasuarina* sp. aff. *distyla* and *Callitris preissii*. Of the many shrub species, none are dominant. Major ground cover species are **Echium plantagineum, Tribulus terrestris* and **Cirsium vulgare*. Each species tends to occur within a range of distances from the river, possibly related to the depth of the water-table and of the alluvium (Figure 3). This community occurs widely to the south of the Merriwa Plains, between 100 and 300 m altitude, and on slopes of zero to 20 degrees.

The vegetation on alluvium, derived wholly or in part from basalt, is structurally similar. The main tree species is *Eucalyptus albens–E. moluccana* with *E. conica, E. melliodora* and *Brachychiton populneus* and occasionally *Callitris preissii* and *E. dealbata*. The main shrub is **Opuntia stricta*. This community is found mainly in the Growee and Bylong rivers, and also through the Merriwa Plains, near "Murrumbo" and "Poggy" and occasionally near lower basalt residuals adjacent to the Goulburn River. Due to erosion of most of the basalt, its influence may be very localized and it may be of colluvial origin. The river flats in the south-west, with soils derived from extensive basalt flows, are the best agricultural soils in the district, and are largely cleared.

This map unit has affinities with riparian vegetation throughout the State, but the species composition here, reflecting the local climate and geology, is distinctive.

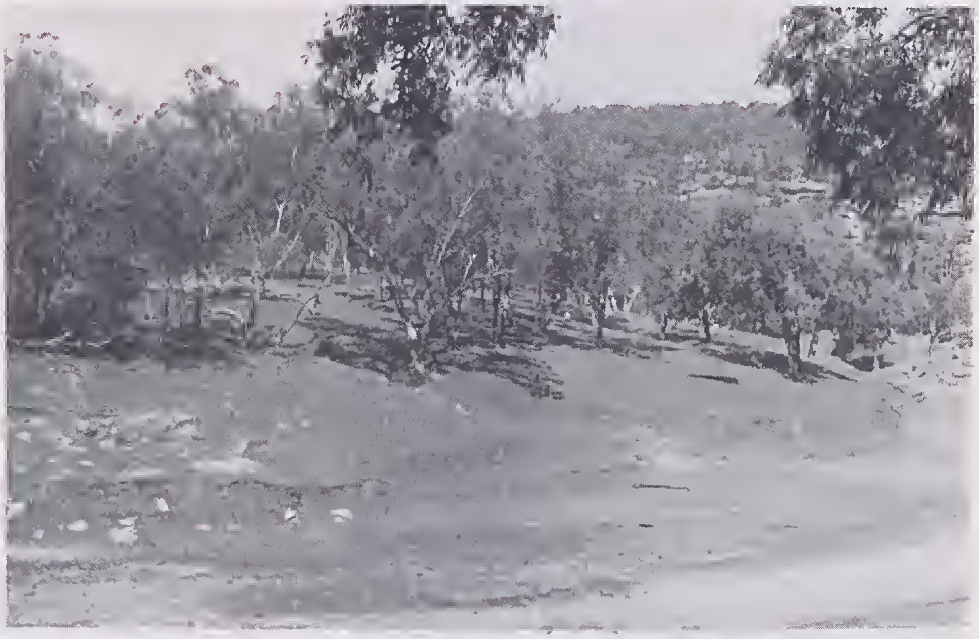

Figure 3. Open-woodland of *Eucalyptus melliodora* and *Angophora floribunda* (Community 3) on broad river flats surrounded by cliffs. Note the almost dry river. Near Morrisons Flat.

4. Woodland in sandstone gullies

In smaller valleys and deeper gullies in the sandstone, grows a woodland in which the main tree species are *Eucalyptus punctata, Acacia linearifolia* and *E. oblonga* and other tree species include *E. fibrosa, E. trachyphloia, Acacia doratoxylon* and *Allocasuarina torulosa*. There is a tall, open shrub layer dominated by *Phebalium squamulosum, Bursaria spinosa, Persoonia linearis* and *Dodonaea triangularis*, and a very sparse ground cover with *Cheilanthes tenuifolia* dominant.

Where the alluvium is derived mainly from siltstone the dominant trees are *Eucalyptus dawsonii* and *Acacia linearifolia*, with *E. crebra* also present. Shrubs include *Dodonaea triangularis, Cassinia cunninghamii, *Opuntia stricta* and the local endemic *Helichrysum tesselatum*. The sparse ground cover contains a diverse mixture of native species, including the very restricted *Goodenia stephensonii*, and agricultural weeds (Figure 4). This form of the community is found generally throughout the sandstone areas, on slopes of 15 degrees, at altitudes of 100 to 350 m, and where exposure of the Permian strata has led to marked widening of the valleys. It is part of Beadle's (1981) *Eucalyptus dawsonii* alliance.

The soil is usually skeletal and sandy, with occasional small alluvial or colluvial deposits. The directions of the creeks are often controlled by joints in the sandstone. Where a creek flows southward or where a valley is deepest and providing good shelter, dense stands of *Backhousia myrtifolia* may occur, for example at Poggy Creek. The overall elevation range is from 150 to 600 m ASL and the slopes can be up to 30 degrees.

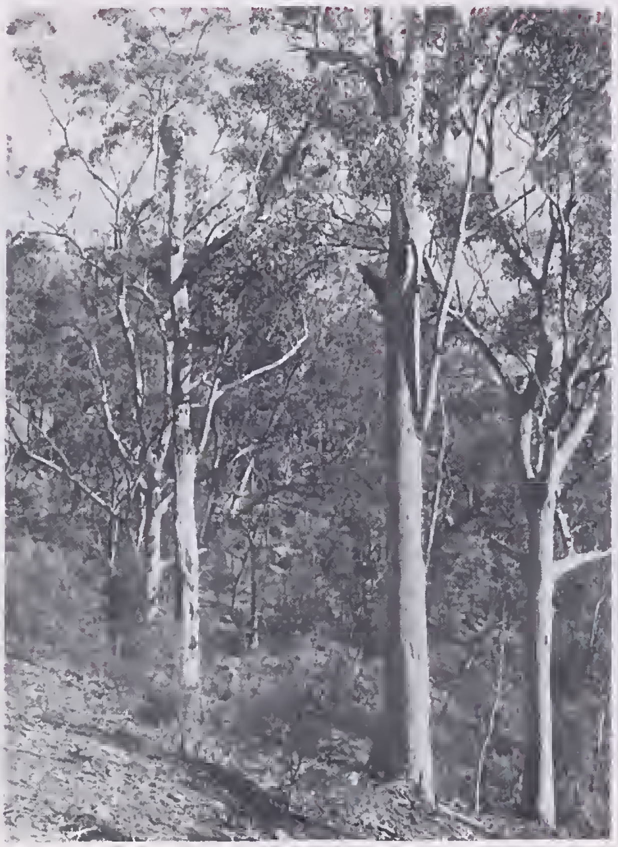

Figure 4. Open-woodland of *Eucalyptus dawsonii* (Community 4) in a siltstone gully near Morrisons Flat. Shrub species are *Cassinia cunninghamii* and *Dodonaea triangularis*.

5. Woodland/low open-woodland/low shrubland on shallow soils on Narrabeen Group

This map unit group contains four communities, three mapped separately.

5a. The shallow soils on the less eroded sandstone ridges and outcrops support a quite distinctive woodland vegetation, characterized by a high density of thin-stemmed trees up to about 12 m high with an open shrub layer. The dominant tree species are *Eucalyptus caleyi* and *Acacia doratoxylon*, commonly associated with *E. trachyphloia* and *Callitris endlicheri*, and occasionally with *E. dwyeri* and *Allocasuarina* sp. aff. *distyla* (Figure 5). *Acacia crassa* replaces *A. doratoxylon* at altitudes over 300 m. The main shrub species are *Persoonia linearis*, *Leptospermum parvifolium*, *Cassinia cunninghamii*, *Leucopogon muticus* and *Philotheca salsolifolia*, while the main ground cover species are *Lomandra glauca*, *Macrozamia communis* and *Cheilanthes tenuifolia*. The altitude of the low sandstone ridges ranges from 150 to 350 m and the convex slopes and numerous rock ledges may be up to 20 degrees in slope, with the steepest slopes below rock ledges. The distribution is generally in the south of the area, from about 10 km south of the Merriwa Plains to Widden, and between Sandy Hollow and Lees Pinch.

5b. On very shallow soils, on watersheds, above cliff-lines and on other exposed sites is a low shrubland dominated by *Philotheca salsolifolia*, *Baeckea densifolia*, *Phebalium squamulosum*, *Calytrix tetragona* and *Leptospermum parvifolium*, often with only two or three species present at any site (Figure 6). This community occurs in small stands scattered throughout the three other associated communities.

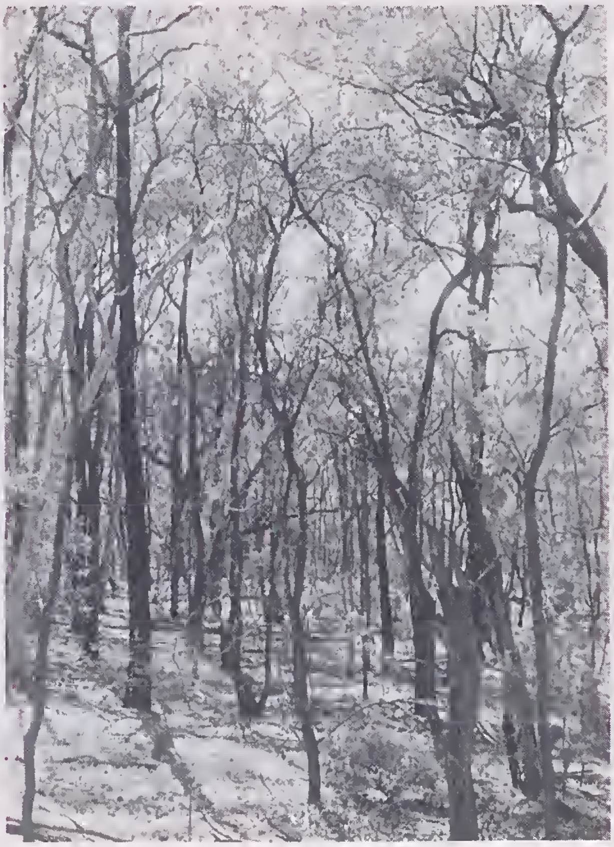

Figure 5. Woodland of *Eucalyptus caleyi* and *Acacia doratoxylon* (Community 5a) on a sandstone ridge near Morrisons Flat. Note the typical open understorey and high stem densities.

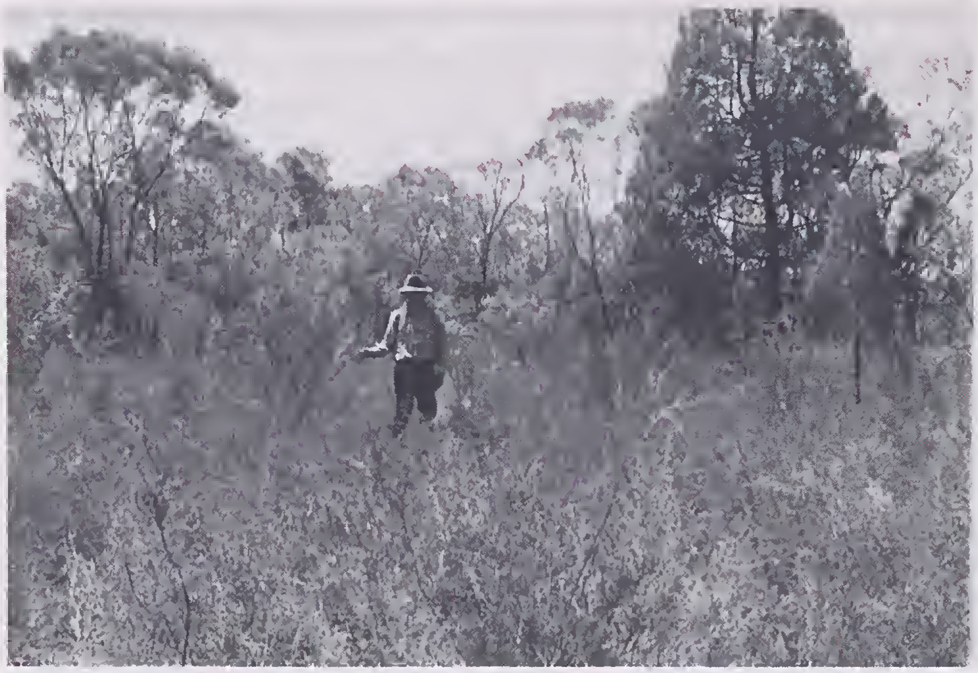

Figure 6. Low shrubland of *Baeckea densifolia, Calytrix tetragona* and *Leptospermum parvifolium* (Community 5b, foreground) on a sandstone ridge near Morrisons Flat. In the background, on a better drained soil, is a woodland of *Callitris endlicheri, Acacia doratoxylon* and *Eucalyptus caleyi* (Community 5a).

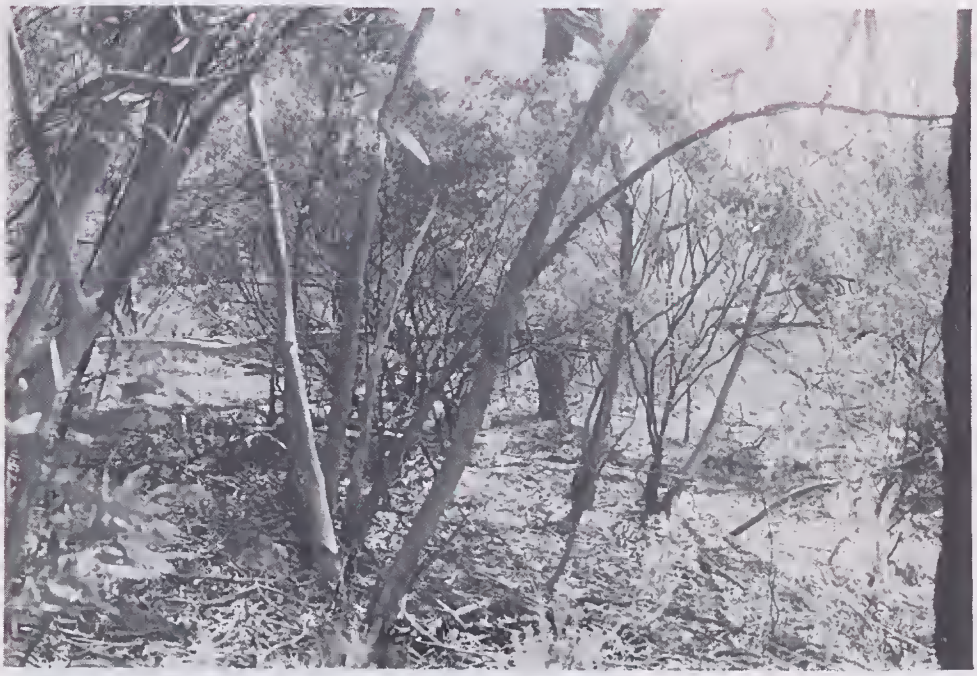

Figure 7. Low woodland of *Eucalyptus dwyeri,* with *Phebalium squamulosum* in the understorey (Community 5e), on an exposed sandstone hill near "Murrumbo".

5c. Skeletal soils on very exposed hilltops and on jointed residuals of higher strata of the Narrabeen Group support a low open-woodland dominated by *Eucalyptus dwyeri* and *E. oblonga,* with other species such as *Callitris endlicheri, E. caleyi, E. punctata, Acacia doratoxylon* and *A. linearifolia* (Figure 7). The understorey is similar to the low shrubland on very shallow soils, described above, but also with *Platysace lanceolata, Eriostemon myoporoides* and *Lomandra* sp. aff. *longifolia.* The species composition of the community varies with soil depth and the degree of exposure. It occurs north of the Goulburn River near Kerrabee and also to the south, extending into the highlands of Wollemi National Park, at altitudes usually over 400 m, and west of the Great Divide.

5d. Around the gorge of the Goulburn River to the west and north-west of Lees Pinch, where the soils are possibly finer textured, is a woodland, in which the dominant trees are *Eucalyptus trachyphloia* and *E. rossii.* Other trees present are *Callitris endlicheri* and *Allocasuarina* sp. aff. *distyla.* This community, found on slopes up to 10 degrees and at 300 to 400 m altitude, occurs widely along the Great Divide in the northwestern corner of the Sydney Basin. The Merriwa district is on the eastern edge of its range.

6. Woodland/open-woodland/open-scrub on deeper soils on Narrabeen Group

This map unit group contains four communities, three of which are mapped separately.

6a. The deeper soils on talus slopes derived from weathered rocks of the Narrabeen Group support a woodland community with a medium density of single-trunked trees up to 15 m high and an open shrub layer. The dominant tree species is *Eucalyptus fibrosa* and, on deeper soils, others such as *Callitris endlicheri, E. punctata* and, occasionally, *E. oblonga* occur. The main shrub species are *Dodonaea triangularis, Acrotriche rigida, Grevillea sericea, Hibbertia monogyna, Acacia triptera* and *A. paradoxa,* while the main ground cover species is *Lomandra glauca.* The distribution is throughout the sandstone areas where the Narrabeen Group is being undercut by the Goulburn River eroding the Permian strata and causing accelerated valley widening. Where this widening occurs north of the Goulburn River, the strata dip into the plateau surfaces and fairly extensive bands of talus develop. To the south of the river, the strata parallel the ridgetops and only the steeper slopes have talus. The altitude ranges from 200 m ASL in the east up to 600 m ASL in the west.

6b. Between the Bow River and Munmurra Brook on low level ridges and broad shallow gullies on deeper sandy soils, at altitudes of 300 to 400 m, is a mixed ironbark community. The dominant species are *Eucalyptus crebra, E. sideroxylon, E. punctata* and *E. fibrosa* with other species including *E. beyeri, E. dwyeri, Callitris endlicheri* and *Allocasuarina luehmannii* present also. Common shrub species are *Acacia triptera, Melaleuca erubescens, M. uncinata, Baeckea cunninghamii, Grevillea sericea* and *Melichrus urceolatus.* A common ground cover species is *Triodia irritans* var. *laxispicata.* The number of tree species at any site varies, reflecting differences in soil, topography and fire history. While this community is locally restricted in distribution, similar vegetation occurs elsewhere in the Western Slopes. *Eucalyptus punctata* and *Allocasuarina luehmannii* are found near watercourses, and this could perhaps be considered physiographically as an extreme variation of the woodland in sandstone gullies (Community 4).

6c. Poorly drained sites support an open-scrub of *Melaleuca uncinata, Allocasuarina* sp. aff. *distyla, Acacia triptera* and *Kunzea ambigua,* with *Lomandra glauca* and *Hibbertia monogyna* dominating the ground cover. This open-scrub is found occasionally north of the Goulburn River, and to the south in the Bylong River valley. It is more abundant in the Bow River valley at 300 to 400 m altitude, associated with Narrabeen Group strata that weather to form a clayey soil.

6d. South-east of "Poggy" is a woodland of *Eucalyptus maculata, E. crebra* and *Callitris endlicheri* on sandstone soil, adjacent to a large basalt flow. With two other similar sites, at Cassilis and Gulgong, this represents the furthest inland extent of the very widespread coastal species, *E. maculata,* which is abundant in the Hunter Valley. The altitude is between 360 and 400 m ASL and the aspect is generally southeasterly.

DISCUSSION

Though the Merriwa district lies in the Central Western Slopes botanical subdivision of the State (see p. 396), its vegetational affinities are with those of five others nearby. As well, the area contains a number of rare, restricted or vulnerable species.

Communities

The plant communities have affinities with those of the Central and North Western Slopes, those of the Central and North Coast and those of the Northern Tablelands. This is a result of the juxtaposition, within the Goulburn River valley, of communities with differing climatic, and thus geographic, ranges. This is a feature of the Goulburn River valley absent from nearby areas. It is caused by a number of physiographic characteristics: the low height of the Great Divide; the low local relief of the plateau (dissected by valleys that have broad river flats); the cliff-lines that are generally not as abrupt as they are elsewhere in the Sydney Basin; and the boundary between the basalt flows and the underlying sedimentary strata that forms a more indistinct margin to the Sydney Basin here, than is usual elsewhere.

Counter to these factors that act to merge the plant communities, the present fire regimes are acting to reinforce the distinctions between the mapped units. There are three distinct fire regimes in the area, of which only the second is not artificially imposed.

Firstly, fires are rare in the remnant vegetation of the basalt plains and the broad river flats, which are subject to the same fire regime as the surrounding agricultural lands.

Secondly, fires are infrequent in the vegetation of the low dissected sandstone plateaux near the Goulburn River; perhaps at intervals of up to 20 years. Evidence for this can be seen in the lack of fire scars on tree trunks and in the absence of charcoal in the leaf litter and in the presence of full skirts of dead leaves on individuals of *Xanthorrhoea johnsonii.* Limited observations suggest that some of the dominant tree species, such as *Eucalyptus caleyi* and *Acacia doratoxylon,* do not resprout after fire, and are thus not fire tolerant.

Thirdly, the highest fire frequencies are in the vegetation on the steeper sandstone slopes separating the alluvial flats from the plateaux. The dominant tree species, such as *E. fibrosa, E. oblonga* and *E. dwyeri,* readily recover from fires. Most fires here start on the edge of the river flats and travel upslope, and are often lit to protect agricultural land or to provide soft regrowth for cattle fodder.

The only vegetation type restricted to the area is that on shallow soils on the Narrabeen Group, dominated by *Eucalyptus caleyi* and *Acacia doratoxylon* Community 5a). It occurs only near the Goulburn River from Sandy Hollow to Lees Pinch.

With the proclamation of the Wollemi and Goulburn River National Parks, in 1980 and 1983 respectively, the conservation status of the flora was greatly improved. These parks, which are generally restricted to those communities that occur on the Narrabeen Group, are large enough to ensure their long-term conservation. Before this, two smaller nature reserves (Manobalai and Munghorn Gap) and a number of State forests (especially Bylong, Durridgere, Nullo Mountain and Turill) were the only lands in the district that included conservation as an objective. The remaining lands are generally unsuitable for conservation and it is unlikely that the current conservation status of the flora will change appreciably in the future.

Species

Many of the species in the area are also found in other parts of the State, and reflect the distribution patterns of the communities in which they occur. The temperate but dry climate influences the local floristic composition of the widespread communities. For example, few of the "rainforest" species found on alluvium along the Hunter River occur along the Goulburn River, while those species on sedimentary strata that are widespread elsewhere in wetter areas, tend to be restricted to gullies, while those from drier areas tend to occur on exposed ridges and plateaux.

The eucalypts show a range of distribution patterns. Two species, *Eucalyptus conica* and *E. trachyphloia*, found on the Narrabeen Group here, are not found elsewhere in the Sydney Basin. There are three common integradations between related taxa: between *E. blakelyi* (SNEEFA, coding from Pryor & Johnson, 1971) from the west and *E. tereticornis* (SNEEB) from the east; between *E. albens* (SUL:G) and *E. moluccana* (SUL:B), depending on local topography and soil; and between the two subspecies of *E. fibrosa*, subsp. *fibrosa* (SUP:AA) and subsp. *nubila* (SUP:AB). Some minor discontinuites in distribution occur — *E. maculata*, which is generally on the coast and in the nearby Hunter Valley, occurs in the district as a number of isolated populations. To the south, *E. sideroxylon* is not found until the Tertiary alluvium in the Nepean River valley is reached.

Of the 24 species of *Acacia* in the area, nine, including many of the more abundant species, are only found west of Denman or Scone, and most of these are distributed through the North Western Slopes and south-east Queensland. They are *Acacia armata*, *A. crassa*, *A. deanei* subsp. *deanei*, *A. decora*, *A. doratoxylon*, *A. gladiiformis*, *A. ixiophylla*, *A. muellerana* and *A. subulata*.

Callitris preissii subsp. *preissii* has a notably large disjunction in its distribution; it is found in Victoria, South Australia and Western Australia, but in New South Wales only in the Goulburn River valley.

Rare and restricted species. A number of rare or restricted species have been recorded for the study area. Species that have a restricted distribution and are considered to be endangered because of their small population sizes include:

- *Cynanchum elegans* (Asclepiadaceae), a vine recorded from only three locations (though not found during this study): Native Vineyard, north of Cobbitty; Kooragang ("Ash") Island and in the lower Hunter River; and Mt Dangar, in the Goulburn River National Park. The first two sites have been largely disturbed, and the species may now be extinct there (A.N. Rodd, pers. comm.).
- *Kennedia retrorsa* (Fabaceae), a large vine recorded from the slopes below Mt Dangar on sandstone soil and colluvium. The other recorded location, the Blacktown Tablelands in central Queensland, being so remote from Mt Dangar, suggests that the two locations are relicts of a once wider range.

- *Rylstonea cernua* (Myrtaceae), an erect shrub found on level sandy ridgetop areas, amongst rocky outcrops, in low open-woodland of *E. fibrosa, Callitris endlicheri* and *E. dwyeri.* Known localities are: Goonoo State Forest near Dubbo; near Widden; and Lees Pinch. It is endangered because its small populations are vulnerable to general developments such as road works.

Rare species with a very restricted distribution, but which are not endangered or vulnerable at present include:

- *Acacia* sp. aff. *decurrens* (Mimosoideae), a newly recognized and as-yet undescribed species, occurring only on the basalt slopes of Mt Dangar, where it grows as a common small tree up to 8 m high with *E. albens.*
- *Callistemon* sp. aff. *shiressii* (Myrtaceae), possibly a new species (J. Powell, pers. comm.), is found only on the banks of the Goulburn River near Kerrabee, mostly within the National Park (two records at National Herbarium of New South Wales).
- *Helichrysum tesselatum* (Asteraceae), an erect shrub found in woodlands of *Eucalyptus dawsonii* or *E. punctata,* on talus of Narrabeen sandstone or Permian siltstone. Herbarium collections are all within the study area: "Murrumbo" (type locality, status unknown); Coxs Gap (in Wollemi National Park, near a road easement); and "Goulburn River, north of 'Murrumbo' ", which includes Morrisons Flat, where it is common. Though it is in places threatened by grazing, agriculture and logging, it is well represented in the National Park.
- *Lasiopetalum longistamineum* (Sterculiaceae) is a shrub found only on or near Mt Dangar (not recorded during this study).

Two vulnerable species with broad ranges but specific habitats were recorded:

- *Goodenia stephensonii* (Goodeniaceae) is an erect woody herb found in open-forests on Permian siltstones under *E. dawsonii.* Localities for herbarium collections are Denman–Baerami; Lees Pinch; Wollar–Muswellbrook; "Goulburn River"; Gosford; and Maffra in Victoria (the last possibly an inaccurately labelled specimen). The distribution is remarkably disjunct, and whether the species still occurs outside the Goulburn Valley is uncertain. It is common at Morrisons Flat, but must be considered a vulnerable species due to its scattered occurrences.
- *Grevillea johnsonii* (Proteaceae) is a tall, spreading shrub found in open areas above or below cliff-lines and in canyons; in open-woodland (Community 4) or low open-woodland (Community 5) respectively. It is known from Bylong to Sandy Hollow, including Widden and Mt Dangar, and near Capertee. This species is vulnerable due to its specific habitats and the effects of possible land use changes.

Additionally, certain taxa recorded in the area might be assigned to new species. These are:

- *Lomandra confertifolia* (Xanthorrhoeaceae) is widespread, but might contain a new species (A. Lee, pers. comm.), which could be confined to the study area, in which case it would be a restricted species.
- *Eucalyptus* sp. aff. *oblonga* (MAHEO; Myrtaceae) was found in two locations in the west of the area — Kellys Gap and the head of Councils Creek. The species occurs in limited stands near the western margin of the Narrabeen Group, from Kellys Gap to Capertee, Megalong and Kanimbla valleys (L.A.S. Johnson & D. Blaxell, pers. comm.). As it only occurs in small scattered populations it could be rare or vulnerable.

One species, *Acacia murrumboensis,* which was previously considered to be rare and restricted, is now considered to be a form of *A. linearifolia* (M. Tindale, pers. comm.).

Many of these species occur on Mt Dangar or Morrisons Flat, two areas that offer unusual habitats, the former being an isolated hill and the latter an area of incipient valley widening. The former and part of the latter are in the Goulburn River National Park, while part of the latter is leasehold grazing land.

Species richness. A total of 306 species was recorded during this study (Appendix 2). As most of the collecting was during the summer and during a prolonged drought, and also as the study was directed at identifying species associations, this species list is incomplete. It is probably comprehensive for the shrub and tree species, but incomplete for the herbaceous species. Further coverage is provided by Dorman (1972), who recorded 340 species, over nine years from a number of specific locations.

ACKNOWLEDGMENTS

The authors wish to thank the officers of the Water Resources Commission for use of aerial photography and other information; the staff of the National Herbarium of New South Wales for identification of specimens, information on undescribed taxa and comments on the manuscript, especially D. Benson, who also gave much encouragement and advice; and the residents of the district, who gave willing assistance.

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APPENDIX 1

Floristic list for the Merriwa 1:100 000 map sheet, compiled from field records from this survey only. Other lists for the district are Baker (1896) and Dorman (1972). The major groups are arranged systematically — Pteridophyta, Gymnospermae and Angiospermae, and within the latter, Monocotyledons and Dicotyledons. Familes, genera and species are arranged alphabetically. Exotic species are marked with an asterisk (*). The map units in which each species was found are indicated, and are numbered as in the text. Bold type indicates that the species is important in that unit. Growth habit codes are: F=fern; H=herb; S=shrub; T=tree; V=vine; and any left-hand character indicates size: L=large; S=small (e.g. ST=small tree). Species names are those currently recognized at the National Herbarium of New South Wales (mostly as in Jacobs & Pickard, 1981).

PTERIDOPHYTA

- ADIANTACEAE
  - *Adiantum aethiopicum* (F) 2
  - *A. hispidulum* (F) 1 4
  - *Cheilanthes distans* (F) 3
  - *C. tenuifolia* (F) **1** 3 **4 5 6**
  - *Pellaea falcata* (F) 2
- ASPLENIACEAE
  - *Asplenium flabellifolium* (F) 1 5 6
- POLYPODIACEAE
  - *Pyrrosia rupestris* (F) 1

GYMNOSPERMAE

- CUPRESSACEAE
  - *Callitris endlicheri* (ST) **1** 2 **3 5 6**
  - *C. preissii* subsp. *preissii* (ST) 3 5
- ZAMIACEAE
  - *Macrozamia communis* (S) 4 5 6
  - *M. pauli-guilielmii* subsp. *plurinervia* (S) 6

ANGIOSPERMAE

MONOCOTYLEDONS

- COMMELINACEAE
  - *Commelina cyanea* (H) 3 4
- CYPERACEAE
  - *Gahnia aspera* (G) 5 6
  - *Lepidosperma laterale* (G) 5 6
  - *L. lineare* (G) 6
  - *L. viscidum* (G) 6
  - *Schoenus ericetorum* (G) 6
- IRIDACEAE
  - *Patersonia sericea* (G) 6
- LILIACEAE
  - *Dianella revoluta* (G) 5 6
  - *Stypandra glauca* (G) 5 6
  - *Thysanotus tuberosus* (G) 5
- PHILESIACEAE
  - *Eustrephus latifolius* (V) 1

POACEAE
Aristida ramosa (G) 3
Digitaria parviflora (G) 3
Echinopogon caespitosus (G) 3
**Eleusine indica* (G) 3
Entolasia stricta (G) 6
Dimorphochloa rigida (G) 5
Microlaena stipoides (G) 3
Paspalidium radiatum (G) 1
Stipa sp. (G) 3
Triodia irritans var. *laxispicata* (G) 6
(Other spp. (G) 1 2 6)
XANTHORRHOEACEAE
Lomandra confertifolia (G) 5
L. filiformis (G) 5
L. glauca (G) 1 3 **5 6**
L. sp. aff. *longifolia* (G) 4 **5** 6
L. multiflora (G) 4
Xanthorrhoea johnsonii (S) 5
X. media (S) 4

DICOTYLEDONS

ACANTHACEAE
Brunoniella sp. (H) 1
Rostellularia pogonanthera (H) 1
AIZOACEAE
Tetragonia tetragonioides (H) 4
AMARANTHACEAE
**Amaranthus* sp. (H) 3
APIACEAE
Actinotus helianthi (S) 6
Platysace ericoides (S) 5 6
P. lanceolata (S) 5
APOCYNACEAE
Parsonsia eucalyptophylla (V) 4
ASCLEPIADACEAE
**Gomphocarpus fruticosus* (S) 3
Leichhardtia leptophylla (V) 5
Marsdenia rostrata (V) 1
ASTERACEAE
**Aster subulatus* (H) 3
Brachycome sp. (H) 1
Calotis lappulacea (H) 4
Cassinia cunninghamii (S) **2** 4 **5** 6
C. uncata (S) 1
**Centaurea solstitialis* (H) 3
**Conyza albida* (H) 1 3 4
**Cirsium vulgare* (H) 1 3
Helichrysum apiculatum (S) 3
H. tesselatum (S) 4
H. viscosum (S) 3
Olearia elliptica (S) 4
Podolepis jaceoides (H) 6
Pseudognaphalium luteoalbum (H) 3
Senecio lautus (H) 1
S. sp. (H) 3
S. sp. nov. (H) 1
Vittadinia cuneata sens. lat. (H) 4
**Xanthium chinense* (H) 3
X. spinosum (H) 3
BIGNONIACEAE
Pandorea pandorana (V) 4
BORAGINACEAE
**Echium plantagineum* (H) 3
BRASSICACEAE
**Lepidium bonariense* (H) 3
**Sisymbrium officinale* (H) 3
CACTACEAE
**Opuntia aurantiaca* (H) 3 6
O. stricta* (SS) **1 2 3 4 5 6

CAMPANULACEAE
Wahlenbergia gracilis (H) 1
CARYOPHYLLACEAE
**Petrorhagia nanteuilii* (H) 3
CASSYTHACEAE
Cassytha melantha (V) 5 6
C. pubescens (V) 5 6
CASUARINACEAE
Allocasuarina luehmannii (S) 4 6
A. sp. aff. *distyla* (S) 1 3 5 **6**
A. torulosa (ST) 1 **2** 4
Casuarina cunninghamiana (T) **3**
CHENOPODIACEAE
Atriplex semibaccata (TH) 3
**Chenopodium carinatum* (H) 3
C. poygonoides (H) 1 3
Einadia hastata (H) 3 4 6
CONVOLVULACEAE
Dichondra repens (H) 4 5
CRASSULACEAE
Crassula sieberana (H) 3
DILLENIACEAE
Hibbertia acicularis (S) 4 6
H. monogyna (S) 4
H. obtusifolia (S) 5
EPACRIDACEAE
Acrotriche rigida (S) 4
Astroloma humifusum (S) 5 6
Brachyloma daphnoides (S) 3 6
Leucopogon muticus (S) 4 5 6
L. sp. (S) 3 5
Melichrus erubescens (S) 4 6
M. urceolatus (S) **6**
Styphelia triflora (S) 6
S. tubiflora (S) 6
EUPHORBIACEAE
Bertya oleifolia (S) 5
B. sp. (S) 5
Euphorbia drummondii (H) 3
Poranthera corymbosa (S) 4 6
Pseudanthus pimeleoides (S) 5
FABACEAE
CAESALPINIOIDEAE
Cassia barclayana (S) 3
C. eremophila (S) 6
C. odorata (S) 5
FABOIDEAE
Bossiaea rhombifolia subsp. *concolor* (S) 6
Daviesia acicularis (S) 4
D. genistifolia (S) 4
D. squarrosa (S) 4
Desmodium varians (V) 3 4
Dillwynia juniperina (S) 6
D. sericea (S) 5 6
Glycine clandestina (V) 1 4
Gompholobium latifolium (S) 4
G. virgatum var. *aspalathoides* (S) 5 6
Hardenbergia violacea (V) 5 6
Hovea lanceolata (S) 1 4 5 6
Indigofera australis var. *signata* (S) 1 2 4 5
Kennedia retrorsa (V) 3 6
Oxylobium ilicifolium (S) 4 6
Pultenaea flexilis (S) 6
P. foliosa (S) 6
P. microphylla (S) 6
Swainsona galegifolia (TH) 1
MIMOSOIDEAE
Acacia brownii (S) 5 6
A. buxifolia subsp. *buxifolia* (S) 6

A. caesiella (S) 3
A. crassa (S) 5
A. cultriformis (S) 5
_A._ sp. aff. _decurrens_ (ST) 1
A. deanei subsp. _deanei_ (LS) 3 6
A. decora (S) 5
A. doratoxylon (ST) 1 4 5 6
A. falcata (S) 5
A. gladiiformis (S) 6
A. implexa (S) 1 2
A. ixiophylla (S) 4
A. juncifolia var. _juncifolia_ (S) 6
A. linearifolia (ST) 1 2 3 4 5 6
A. muellerana (S) 4
A. obtusifolia (S) 4
A. paradoxa (S) 6
A. penninervis (S) 5
A. subulata (S) 4 5
A. terminalis (S) 6
A. triptera (S) 6
A. ulicifolia (S) 6
A. uncinata (S) 1 4
GERANIACEAE
Geranium sp. (H) 1
GOODENIACEAE
Dampiera lanceolata (S) 4 6
D. purpurea (S) 4 5 6
Goodenia decurrens (H) 6
G. grandiflora (H) 1
G. hederacea (H) 6
G. stephensonii (H) 4
HALORAGACEAE
Gonocarpus elatus (H) 5
G. longifolius (H) 5
Haloragis serra (S) 1
Myriophyllum verrucosum (H) 5
LAMIACEAE
Ajuga australis (H) 1 4
*_Marrubium vulgare_ (H) 3
*_Mentha_ × _cordifolia_ (H) 3
Prostanthera nivea (S) 5
P. ovalifolia (S) 4
P. prunellioides (S) 4
_P._ sp. (S) 5
Salvia sp. (H) 3
LOBELIACEAE
Isotoma axillaris (H) 5
LORANTHACEAE
Amyema cambagei (E) 3
A. miquelii (E) 5 6
A. quandang (E) 3 6
LYTHRACEAE
*_Lythrum hyssopifolium_ (H) 3
MALVACEAE
Hibiscus sturtii (H) 3 4
*_Modiola caroliniana_ (H) 3
Sida corrugata (H) 1 3 4
MENISPERMACEAE
Stephania japonica (V) 4
MORACEAE
Ficus rubiginosa (ST) 2 5
MYOPORACEAE
Myoporum debile (SS) 3
M. montanum (SS) 1 3
MYRTACEAE
Angophora floribunda (LT) 3 6
Baeckea cunninghanii (S) 6
B. densifolia (S) 5 6
Callistemon linearis (S) 6
C. paludosus (S) 4
C. pinifolius (S) 4
_C._ sp. aff. _salignus_ (S) 4
_C._ sp. aff. _shiressii_ (S) 3 4
Calytrix tetragona (S) 5
Eucalyptus albens (T) 1
E. albens–E. moluccana (T) 1 3
E. beyeri (LT) 6
E. blakelyi (LT) 3
E. caleyi (ST) 5 6
E. camaldulensis (LT) 3
E. conica (T) 3
E. crebra (T) 3 4
E. dawsonii (T) 4 6
E. dealbata (T) 1 3
E. dwyeri (ST) 1 5 6
E. fibrosa subsp. _fibrosa_ (T) 4 6
E. laevopinea (T) 2
E. maculata (T) 6
E. melliodora (LT) 1 2 3
E. moluccana (T) 1 3
E. oblonga (T) 4 5 6
E. punctata (T) 2 4 5 6
E. rossii (ST) 6
E. sideroxylon (T) 6
_E._ sp. aff. _oblonga_ (ST) 6
E. trachyphloia (T) 4 5 6
E. viminalis (T) 2
Kunzea ambigua (S) 4 5 6
Leptospermum attenuatum (S) 5
L. arachnoides (S) 5 6
L. parvifolium (S) 5 6
Melaleuca erubescens (S) 6
M. thymifolia (S) 6
M. uncinata (S) 6
Rylstonea cernua (S) 6
NYCTAGINACEAE
Boerhavia diffusa (V) 3
OLACACEAE
Olax stricta (S) 6
OLEACEAE
Notelaea longifolia (SS) 1 3 4
N. microcarpa (S) 1 6
ONAGRACEAE
*_Oenothera australis_ (H) 3
OXALIDACEAE
Oxalis corniculata (H) 4
PAPAVERACEAE
*_Argemone ochroleuca_ (H) 3
*_Eschscholzia californica_ (H) 4
PHYTOLACCACEAE
*_Phytolacca octandra_ (H) 3
PITTOSPORACEAE
Billardiera scandens (V) 4
Bursaria longisepala (S) 4 6
B. spinosa (S) 1 4
Pittosporum undulatum (S) 2
PLANTAGINACEAE
Plantago sp. (H) 1
POLYGONACEAE
Muehlenbeckia rhyticarya (H) 3
*_Polygonum aviculare_ (H) 3
P. decipiens (H) 3 4
PORTULACACEAE
Calandrinia calyptrata (H) 5
Portulaca oleracea (H) 3
PRIMULACEAE
*_Anagallis arvensis_ (H) 3
PROTEACEAE
Grevillea johnsonii (S) 4 6
G. mucronulata (S) 5

G. sericea (S) 4 5 6
G. triternata (S) 4
Hakea dactyloides (S) 4 5 6
Isopogon dawsonii (S) 4 5 6
Persoonia linearis (S) 4 5 6
Petrophile canescens (S) 5

RANUNCULACEAE
Clematis aristata (V) 1 2 4
C. glycinoides (V) 3

RHAMNACEAE
Alphitonia excelsa (LS) 5
Cryptandra buxifolia (S) 4
C. spinescens (S) 6
Pomaderris ferruginea (S) 4
P. prunifolia (S) 4
P. sp. (S) 4

RUBIACEAE
Asperula scoparia (H) 1
Canthium buxifolium (S) 3
C. odoratum (S) 5
Opercularia diphylla (S) 6
Pomax umbellata (H) 6

RUTACEAE
Boronia anethifolia (S) 5
B. pinnata (S) 5 6
Correa reflexa (S) 1 4
Eriostemon australasicus (S) 5
E. myoporoides (S) 5
Phebalium squamulosum (S) 4 5 6
Philotheca salsolifolia (S) 5 6
Zieria aspalathoides (S) 6
Z. cytisoides (S) 4

SANTALACEAE
Choretrum candollei (S) 1
Exocarpos cupressiformis (ST) 5
E. strictus (ST) 6
Santalum obtusifolium (S) 5

SAPINDACEAE
Dodonaea boroniifolia (S) 5
D. cuneata (S) 5
D. triangularis (S) 3 4 5 6

SCROPHULARIACEAE
Veronica plebeia (H) 1

SIMAROUBACEAE
**Ailanthus altissima* (S) 3 5

SOLANACEAE
**Lycium ferocissimum* (S) 4
**Nicotiana glauca* (S) 3 4
Solanum aviculare (S) 3 4
S. campanula (S) 3 4
S. cinereum (S) 4
S. stelligerum (S) 1
S. vescum (S) 4

STACKHOUSIACEAE
Stackhousia monogyna (H) 4 6

STERCULIACEAE
Brachychiton populneus (T) 1 3
Lasiopetalum ferrugineum var. *cordatum* (S) 4
L. macrophyllum (S) 4
Rulingia pannosa (S) 5

STYLIDIACEAE
Stylidium glandulosum (S) 5
S. laricifolium (S) 5

THYMELAEACEAE
Pimelea hirsuta (S) 4
P. linifolia (S) 5

URTICACEAE
Urtica incisa (H) 3

VERBENACEAE
Clerodendrum tomentosum (S) 2

VIOLACEAE
Hymenanthera dentata (H) 1 2

VISCACEAE
Notothixos cornifolius (E) 1 3

VITACEAE
Cayratia clematidea (V) 5 6
Cissus opaca (V) 3

ZYGOPHYLLACEAE
Tribulus terrestris (H) 3

APPENDIX 2

Breakdown of species numbers in major taxonomic groups and the main families. A similar breakdown is given for tree species.

Group	No. of species	No. of tree species
TOTAL	**306**	**35**
Pteridophytes	7	—
Gymnosperms	4	2
Angiosperms	295	33
Monocotyledons	28	—
Poaceae	10	—
Xanthorrhoeaceae	7	—
Dicotyledons	267	33
Asteraceae	20	—
Epacridaceae	9	—
Fabaceae	44	—
Faboideae	19	—
Mimosoideae	24	—
Myrtaceae	39	22
Eucalyptus	21	21
Proteaceae	9	—
Rutaceae	9	—
Solanaceae	7	—
Exotics	28	—

Cunninghamia 1(3), 371–383 (1985)

ASPECTS OF THE ECOLOGY OF A RARE TREE SPECIES, *EUCALYPTUS BENTHAMII,* AT BENTS BASIN, WALLACIA

D.H. Benson

(Accepted for publication 11.5.1984)

ABSTRACT

Benson, D.H. (National Herbarium of New South Wales, Royal Botanic Gardens, Sydney, New South Wales, Australia 2000) 1985. Aspects of the ecology of a rare tree species, Eucalyptus benthamii, *at Bents Basin, Wallacia. Cunninghamia 1(3), 371–383.* Measurements of the population size and structure of the rare tree species, *Eucalyptus benthamii,* at Bents Basin, Wallacia, New South Wales, together with general observations made over a period of nearly 50 years, indicate that at this site the species is endangered by environmental changes associated with adjacent rural and urban development, particularly through increases in nutrients and exotic weeds and by frequent burning. Ways by which management may enable it to survive there are suggested.

INTRODUCTION

Eucalyptus benthamii Maiden & Cambage (Camden White Gum) is a tree of restricted distribution in coastal New South Wales, occurring naturally only in an area to the south-west of Sydney. Its survival in some localities is in doubt; it is included in the rare or threatened Australian plants list of Leigh, Briggs & Hartley (1981) and in Pryor's (1981) list of endangered eucalypts. The species is coded SPIKQ and placed in Series Viminales, Subseries Viminalinae, by Pryor & Johnson (1971). The most closely related species appear to be *Eucalyptus "dorrigoensis",* which has previously been regarded as a variety of *E. benthamii* but is now considered a separate taxon (L.A.S. Johnson, pers. comm.), and *E. kartzoffiana.* Both species have relatively restricted distributions; *E. "dorrigoensis"* is found near Dorrigo on the North Coast and *E. kartzoffiana* near Araluen on the South Coast of New South Wales.

The original habitat for *Eucalyptus benthamii* was to the south-west of Sydney, on the flats of the Nepean River and its tributaries, particularly Coxs River. Since the arrival of European man, most of this habitat has been cleared for agriculture or submerged beneath the waters of Warragamba Dam. Today, one small population and a number of scattered individuals occur along the Nepean River between Wallacia and Camden (Figure 1). Another larger population is on Kedumba Creek (33° 49′S, 150° 22′E) about 5 km upstream from the junction with the old Coxs River. The Coxs River is now flooded by Lake Burragorang.

The population on the Nepean River is at Bents Basin, 8 km south of Wallacia, and is partly included in the Bents Basin State Recreation Area. Following a major bushfire there in December 1979, a study was begun to provide management guidelines for its survival in this locality.

THE BENTS BASIN POPULATION

Site description

The main stand of *Eucalyptus benthamii* at Bents Basin is confined to parts of a sandy ridge between the Nepean River and a normally dry flood channel, and to the western riverbank (33° 05′S, 150° 38′E). The stand on the sandy ridge is dominated

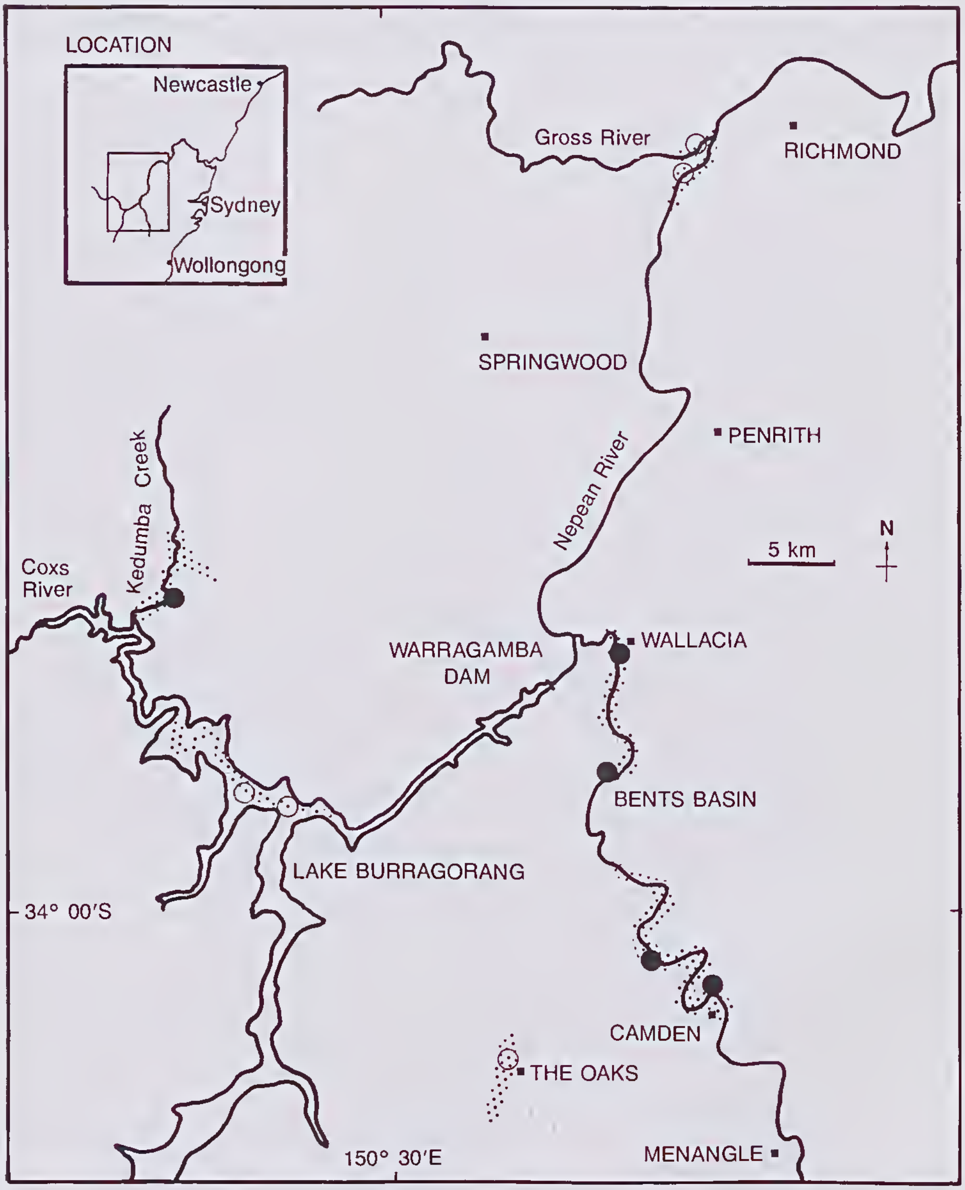


Figure 1. Presumed original distribution of *Eucalyptus benthamii* (dotted). Collection sites for herbarium specimens where the species still exists (●) or is now extinct (○) are shown.

by large, old trees up to 40 m high with stem diameters up to 1.5 m (Figure 2). After 1964 and prior to 1979, there was a tall shrub layer of *Acacia binervia* (formerly known as *A. glaucescens*) and a ground cover of smaller shrubs, many of which were exotic weed species. The *E. benthamii* trees on the riverbank are generally much smaller than those on the sandy ridge. A fire in 1979 severely affected the large trees on the sandy ridge, scorching the crowns of many and killing the *Acacia* shrub layer. The riverbank trees were not affected by that fire but were subsequently burnt by a hot ground fire in 1981.

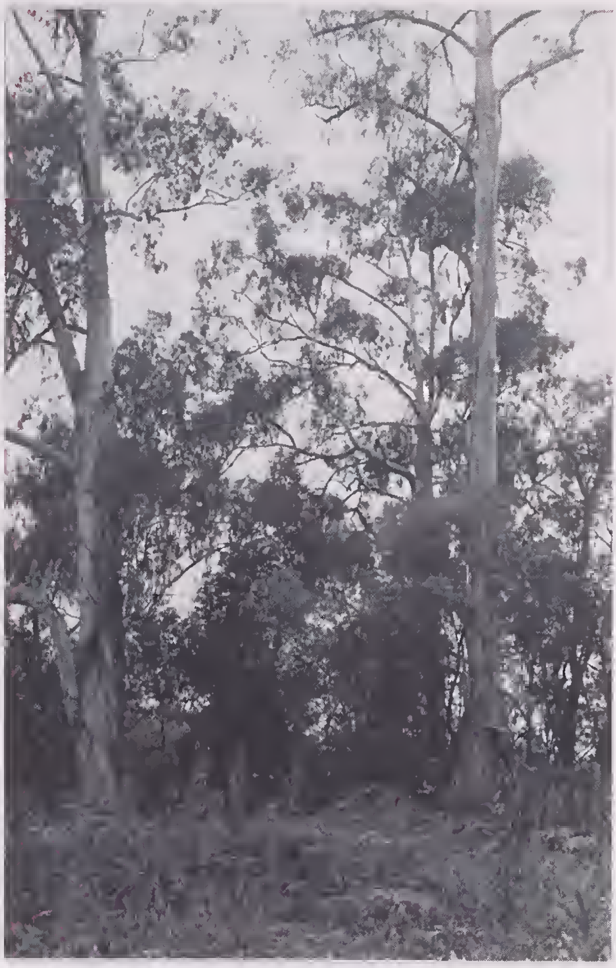


Figure 2. Large old trees of *Eucalyptus benthamii* prior to the 1979 fire.

Methods

Population number and size classes, phenology, and flood and fire patterns were examined. All individuals of *E. benthamii* were measured (diameter at breast height), including specimens of known age. Flowering and fruiting times (phenology) were recorded from specimens held at the National Herbarium of New South Wales and noted in the field. Shortly after the 1979 fire, a 200 × 10 m transect was run along the sandy ridge through the *E. benthamii* stand. Stems (>5 cm d.b.h.) of all species were measured. Soil was augered at 30 m intervals along the 200 m transect and depth, texture, colour and pH were recorded.

Data on past flood heights at Wallacia and Camden were obtained from the Metropolitan Water Sewerage and Drainage Board. Observations on flood and fire patterns since 1933 were given by a local resident, Mr R.S. Venables.

Population size and age

The present population at Bents Basin is of about 100 individuals, most of which are single-stemmed trees although some have two or three main stems. Stem diameter/frequency classes are shown in Figure 3a. Most of the dead stems resulted from the 1979 fire and, as the measuring was done soon after the fire, these data may be included with the data from the living trees to give a picture of the stand structure prior to the fire. Two peaks are indicated in Figure 3a, a major peak for the 11–30 cm d.b.h. class and a peak for 80–110 cm d.b.h. The diameter size classes are also shown for two groups of trees from the riverbank, known to have grown following coppicing in 1945 (Figure 3b) and after flooding in 1964 (Figure 3c), respectively (R.S. Venables, pers. comm.). Comparison of these data suggests that the first peak in Figure 3a may be related to tree establishment after the 1964 flood.

Maiden & Cambage (1914) in their description of the species include references to trees up to 180 cm d.b.h., sizes commensurate with the largest trees present today. Herbarium notes for collections at the National Herbarium, other than those at Bents Basin, refer to smaller trees. A number of collections have no information. (There may be a bias towards collecting specimens from smaller trees because of easier accessibility.) The large trees at Bents Basin have remained largely unchanged since the 1880s (pers. comm. of old resident to R.S. Venables in 1930s), though the canopies of some are now deteriorating, hastened by the recent fire.

Phenology

Buds are found on some trees at any time of the year except February. Flowering takes place in April–May and mature fruit has been collected between April and June, and October and December. Flowering and fruiting abundance seems to vary considerably between individuals. Freshly collected seed has good viability. Under natural conditions, young trees 5 m high, and probably only 6 to 10 years old, may produce mature seed capsules.

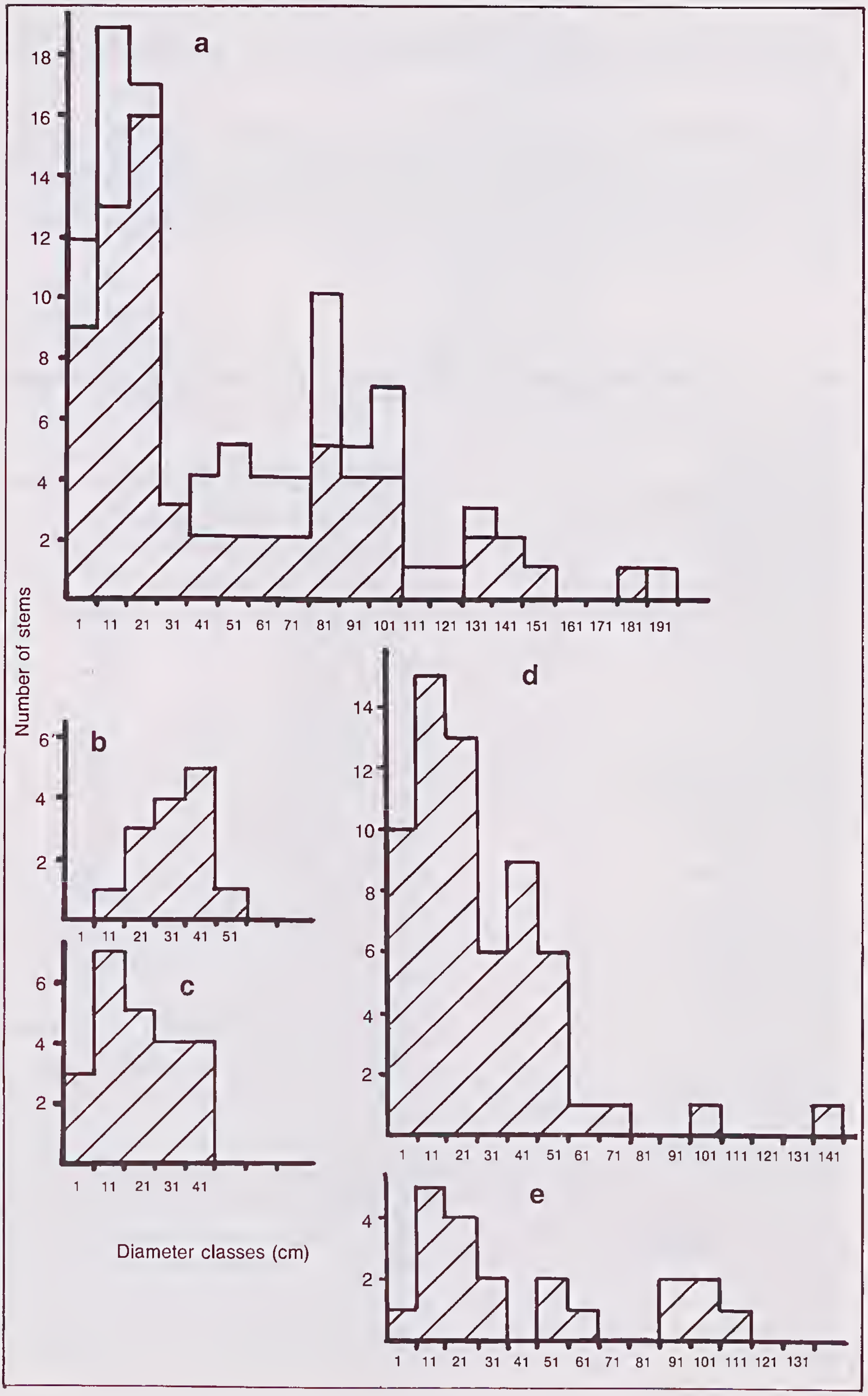
Associated species

Native. Table 1 lists species associated with *Eucalyptus benthamii.* The main tree species is the quick-growing riparian *E. elata* (River Peppermint), which grows to about half the size of *E. benthamii.* Tree species that occur sporadically are *Angophora subvelutina, Eucalyptus saligna, E. tereticornis* and *E. baueriana;* these tend to be more abundant on alluvium further from the river.

In 1977 the understorey associated with the *E. benthamii* on the sandy ridge included tall shrubs of *Acacia binervia* and *A. floribunda* (8 to 10 m high) and smaller shrubs such as *Breynia oblongifolia* and *Hymenanthera dentata* (Benson, 1977). Ground cover was discontinuous with patches of *Lomandra longifolia, Pteridium esculentum* and *Cynodon dactylon.* Weed species, including *Olea africana* and *Tradescantia albiflora* were frequent. On the western end of the sandy ridge was scrub of *Acacia binervia* and *A. floribunda.*

The 1979 fire destroyed most of the above ground vegetation, though by February 1980 regeneration by seedlings and resprouting from burnt plants was evident. Of the tall shrubs, only *Acacia binervia* was killed by fire. *Acacia floribunda, A. parramattensis, Hymenanthera dentata* and *Breynia oblongifolia* resprouted from the stem base or suckered from roots. Unfortunately, no quantitative data are available for pre-fire conditions, except the dead stem densities of *A. binervia* recorded after the fire. Stems of *A. binervia* within the *E. benthamii* stand are thicker than those restricted to the scrub ($p < .001$). The smaller stems established from seed

Figure 3. Stem diameter/frequency classes for *Eucalyptus benthamii* (living plants hatched, dead plants unhatched). Populations from a) Bents Basin sandy ridge, b) Bents Basin riverbank coppiced 1945, c) Bents Basin riverbank regeneration 1964, d) and e) Kedumba Creek (two stands). (Vertical axis is number of stems, horizontal axis is diameter class in cm.)


a
18
16
14
12
10
8
6
4
2
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161 171 181 191
Number of stems
b
6
4
2
1 11 21 31 41 51
c
6
4
2
1 11 21 31 41
Diameter classes (cm)
d
14
12
10
8
6
4
2
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141
e
4
2
1 11 21 31 41 51 61 71 81 91 101 111 121 131

after the 1964 flood. Establishment was also noted after the 1949 flood. (R.S. Venables, pers. comm.). *Acacia binervia* also establishes after fire, and prolific germination followed the 1979 fire. It is likely that the larger stems germinated after the 1957 fire.

Exotic. Exotic species are a major component of the understorey associated with *E. benthamii.* Of the 36 recorded (Table 1), about two-thirds are cosmopolitan weeds (predominantly annuals or short-lived perennials of agricultural situations, disturbed ground, roadsides, etc.) and a third are garden exotics (commonly perennials, often woody shrubs) with the ability to invade relatively undisturbed bushland. Both types respond vigorously to increases in available nutrients.

TABLE 1

Native and exotic species associated with _Eucalyptus benthamii_ at Bents Basin, Wallacia. Exotic species of garden escape (G) or agricultural/cosmopolitan origin (A) are indicated.

PTERIDOPHYTES
ADIANTACEAE
Adiantum aethiopicum
DENNSTAEDTIACEAE
Pteridium esculentum

DICOTYLEDONS
ACERACEAE
*_Acer negundo_ G
ASCLEPIADACEAE
*_Araujia hortorum_ G
ASTERACEAE
*_Bidens pilosa_ A
*_Bidens subalternata_ A
Calotis dentex
*_Chondrilla juncea_ A
*_Conyza albida_ A
*_Gnaphalium sphaericum_ A
*_Hypochaeris radicata_ A
Senecio hispidulus
*_Senecio mikanioides_ A
*_Tagetes minuta_ A
*_Xanthium chinense_ A
APIACEAE
*_Foeniculum vulgare_ G
BORAGINACEAE
Cynoglossum australe
Ehretia acuminata
BRASSICACEAE
*_Rapistrum rugosum_ G
CACTACEAE
*_Opuntia_ sp. G
CAMPANULACEAE
Wahlenbergia gracilis
CARYOPHYLLACEAE
Polycarpum tetraphyllum
Stellaria flaccida
*_Stellaria media_ A
CHENOPODIACEAE
Chenopodium ambrosioides
*_Chenopodium carinatum_ A
Einadia hastata
CYPERACEAE
Gahnia sp.
EUPHORBIACEAE
Breynia oblongifolia
Phyllanthus gasstroemii

FABACEAE
Acacia binervia (Mimosoideae)
Acacia floribunda (Mimosoideae)
Acacia obtusifolia (Mimosoideae)
Acacia parramattensis (Mimosoideae)
*_Gleditsia triacanthos_ (Caesalpinioideae) G
Glycine sp. (Faboideae)
Kennedia rubicunda (Faboideae)
LOBELIACEAE
Pratia purpurescens
MALVACEAE
*_Modiola caroliniana_ A
Sida rhombifolia
MELIACEAE
Melia azedarach var. _australasica_
MENISPERMACEAE
Stephania japonica var. _discolor_
MYRTACEAE
Angophora subvelutina
Backhousia myrtifolia
Eucalyptus benthamii
Eucalyptus elata
OLEACEAE
*_Ligustrum sinense_ G
*_Olea africana_ G
PASSIFLORACEAE
Passiflora herbertiana
*_Passiflora subpeltata_ G
PITTOSPORACEAE
Bursaria spinosa
Hymenanthera dentata
Pittosporum revolutum
POLYGONACEAE
*_Acetosa sagittata_ A
*_Acetosa vulgaris_ A
Rumex brownii
*_Rumex crispus_ A
RANUNCULACEAE
Clematis aristata
RUTACEAE
Eriostemon myoporoides
SANTALACEAE
Santalum obtusifolium
SCROPHULARIACEAE
*_Verbascum virgatum_ A
Veronica plebeia

SOLANACEAE
**Datura stramonium* A
**Solanum gracilius* A
**Solanum nigrum* A
**Solanum prinophyllum* A
**Solanum pseudocapsicum* A
STERCULIACEAE
Brachychiton populneum
URTICACEAE
Urtica incisa
VERBENACEAE
Clerodendron tomentosum
VITACEAE
Cayratia clematidea

MONOCOTYLEDONS
ASPARAGACEAE
**Asparagus officinalis* G
**Myrsiphyllum asparagoides* G
COMMELINACEAE
Commelina cyanea
**Tradescantia albiflora* G
DIANELLACEAE
Dianella laevis
LOMANDRACEAE
Lomandra longifolia
PHILESIACEAE
Geitonoplesium cymosum
POACEAE
**Bromus unioloides* A
**Cynodon dactylon* A
Echinochloa sp.
Entolasia marginata
Microlaena stipoides
Oplismenus aemulus
Paspalidium sp.
**Setaria geniculata* var. *pauciseta* A

TABLE 2

Dates and heights of major floods on Nepean River at Menangle (1806–1900) and Wallacia since 1870

Date of flood		Height above standard datum (m)	
Year	Month	Menangle	Wallacia
1806	August	69.4	—
1864	June	75.9	—
1873	February	77.9	47.0
1891	June	72.9	—
1892	September	72.2	—
1893	January	71.4	—
1894	March	71.9	—
1895	February	74.5	—
1897	June	72.7	—
1898	February	77.0	—
1899	July	71.3	—
1900	July	75.1	42.4
1925	June	—	37.2
1949	June	—	38.4
1952	July	—	36.9
1956	February	—	38.1
1961	November	—	41.5
1964	June	—	44.2
1975	June	—	38.7
1978	March	—	42.4

Flood patterns, soil and effects on germination

Table 2 gives the height and date (year and month) of the highest recorded floods. Floods may occur at almost any season, though they are most frequent in June–July.

The sandy ridge is at least 2 m deep and underlain by red clay deposits that are exposed along the eastern bank of the river and at the south-eastern side of the sandy bank. Much of the sand is reported to have been deposited during a succession of floods in 1949 (R.S. Venables, pers. comm.). In general, a big flood fills the river with sand, and small floods scour it out. The frequency of small floods has decreased since 1933 when Nepean Dam was completed, resulting in a build-up of driftwood and sand (R.S. Venables, pers. comm.).

Seedlings of *E. benthamii* have been observed to germinate only once since 1933, in the silt deposited by the 1964 flood (R.S. Venables, pers. comm.). Whilst the

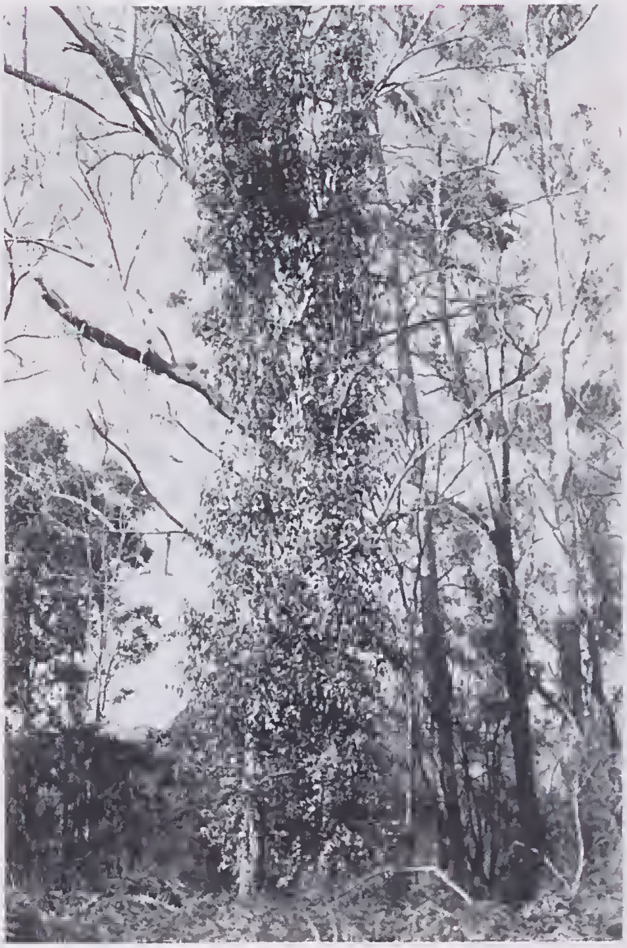


Figure 4. Burnt small tree of *E. benthamii* with regenerating epicormic foliage. Unburnt tree in background.

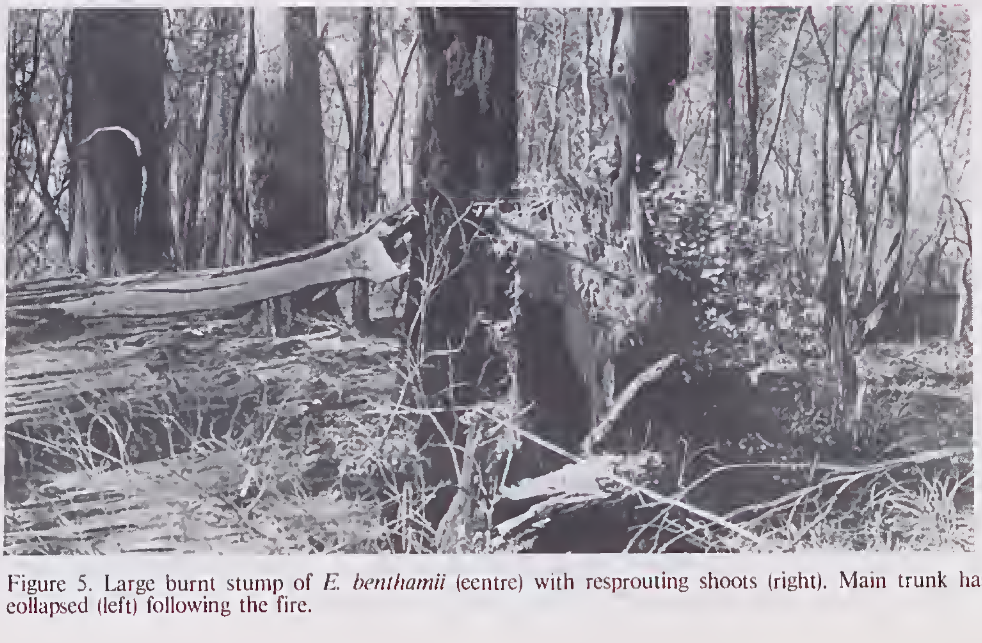


Figure 5. Large burnt stump of *E. benthamii* (centre) with resprouting shoots (right). Main trunk has collapsed (left) following the fire.

1964 flood was the second highest on record (the highest was in 1873), there have been a number of floods that would have flooded the bases of most of the present population of *E. benthamii*, and therefore at least have given possible conditions for germination.

Fire patterns and effect on *E. benthamii*

Since 1933, three fires have affected the *E. benthamii* population; a small creeping fire in December 1957, a major hot fire in December 1979 and a hot ground fire in October 1981, the last two burning different parts of the population (R.S. Venables, pers. comm.).

The intensity of the 1979 fire was high, causing crown scorching in some of the large 40-m-high trees. Mature *E. benthamii* reacts to fire by producing epicormic shoots along the trunk and major branches and/or resprouting from the base of the trunk (Figures 4, 5). Small stems less than 20 cm d.b.h. may be killed by fire, while stems larger than 10 to 20 cm d.b.h. may produce epicormic shoots that grow to re-form the canopy. In 1979, some trees of all sizes were killed outright and the ultimate recovery of some of the large old trees, although showing epicormics at first, is unlikely. Old stumps, however, may resprout. One had a ring of six sucker stems with diameters ranging from 9 to 23 cm, all but one of which were killed by the 1979 fire. Suckers from old stumps have the ability to reach tree size. One coppice or sucker stem that had grown from an old stump (150 cm diameter) was 32 m high with a 54 cm diameter. Fire had weakened it at its junction with the old stem and caused its collapse. The original main stem, also lying on the ground, had been 40 to 45 m high. A nearby stump had a sucker stem with a diameter of 145 cm and a height of 43 m. This stem was leaning and appeared susceptible to future fire damage at the base. It collapsed four years later, possibly during a storm. The theoretical immortality of a series of sucker stems from a damaged stump appears to be limited by the cumulative damage to the base caused by recurring fire (Figure 6).

Fire does not appear to stimulate seedling establishment as it does in *Acacia binervia*. Only one seedling of *E. benthamii* appeared to establish after the 1979 fire, but after reaching about 10 cm in height, it was lost within two years in a rapidly growing thicket of 2 m high *Acacia binervia*.

THE KEDUMBA POPULATION

The population of *E. benthamii* at Kedumba is several times larger than that at Bents Basin and consists of stands of trees up to 30 m high, almost all single-stemmed and generally looking younger than those at Bents Basin. There is the general impression of a number of groups of even-aged trees though this is not as marked as at Bents Basin (Figure 3d, e). The stands of *E. benthamii* are almost pure with only occasional trees of *E. deanei* (Deane's Gum). Ground cover is grassy and open with patches of *Imperata cylindrica* and occasional shrubs such as *Leptospermum flavescens*. With the exception of a few agricultural/cosmopolitan species there are virtually no exotic weeds. Stands occur above the top water-storage level in Lake Burragorang and appear to have been unaffected by the construction of Warragamba Dam. There are no indications of recent floods in Kedumba Creek nor any recent evidence of bushfire; the only burn marks noted suggested a light fire many years ago. The relative absence of fire may be related to the Water Board Catchment prohibitions on access. Adjacent land has been cleared and used for grazing and there is a vigorous stand of young saplings of *E. benthamii* on sandy loam exposed during recent clearing by bulldozer, amongst some of the large *E. benthamii* trees. As the best known stands here are on private property, protection of these from clearing should be a matter of major concern.

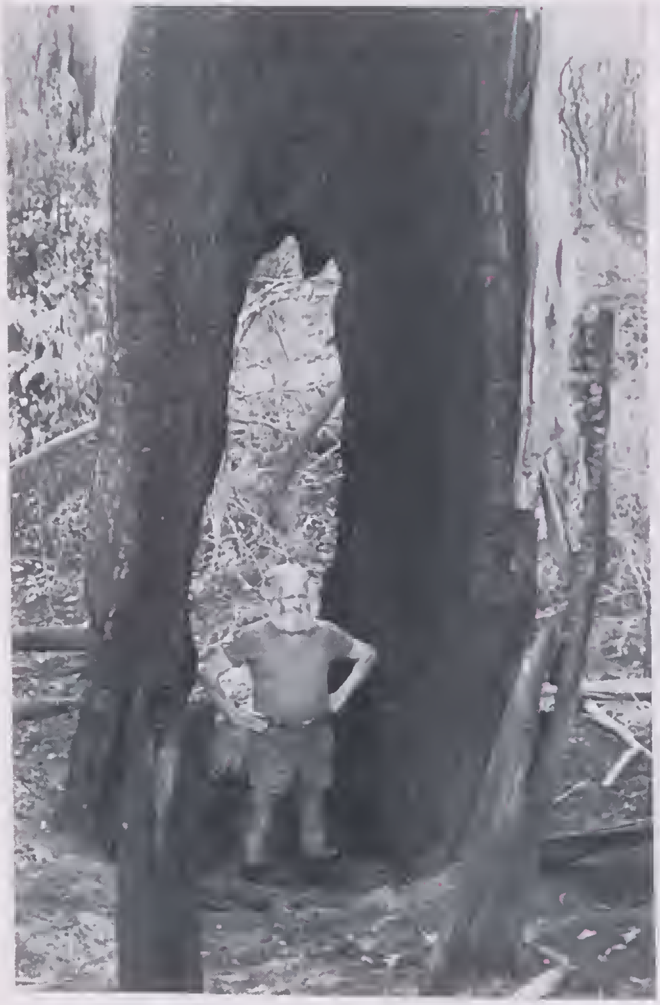


Figure 6. Hollow base of large tree showing cumulative fire damage. Such trees are susceptible to storm damage. Figure is R.S. Venables.

ECOLOGY AND MANAGEMENT OF *EUCALYPTUS BENTHAMII* AT BENTS BASIN

At Bents Basin the ecology of *E. benthamii* involves cycles of flood and fire. The species appears to have a life expectancy as a tall single-stemmed tree of possibly over 150 years, after which, weakened at the base by fire, it may collapse, to regrow a coppice stem that may survive for another 100 years or so (Figure 7). Growth of further stems may be possible, giving the individual plant a life of at least 250 years and possibly more. Other *Eucalyptus* species such as *Eucalyptus regnans* (Mountain Ash), a fire-sensitive tree species, may live for 300 to 400 years (Ashton, 1981).

The population at Bents Basin appears to consist of individuals from two or possibly three recruitment periods. The most recent followed a flood in 1964, and it is likely that the other periods were associated with major floods early last century. For management purposes, the evidence suggests that the need for establishment of more trees might not be expected until after the year 2050, and that current management should aim to protect the young 1964 trees, which should survive until then. In contrast, individuals of the associated but shorter lived *Eucalyptus elata*, which came up as seedlings in 1940, are now dying.

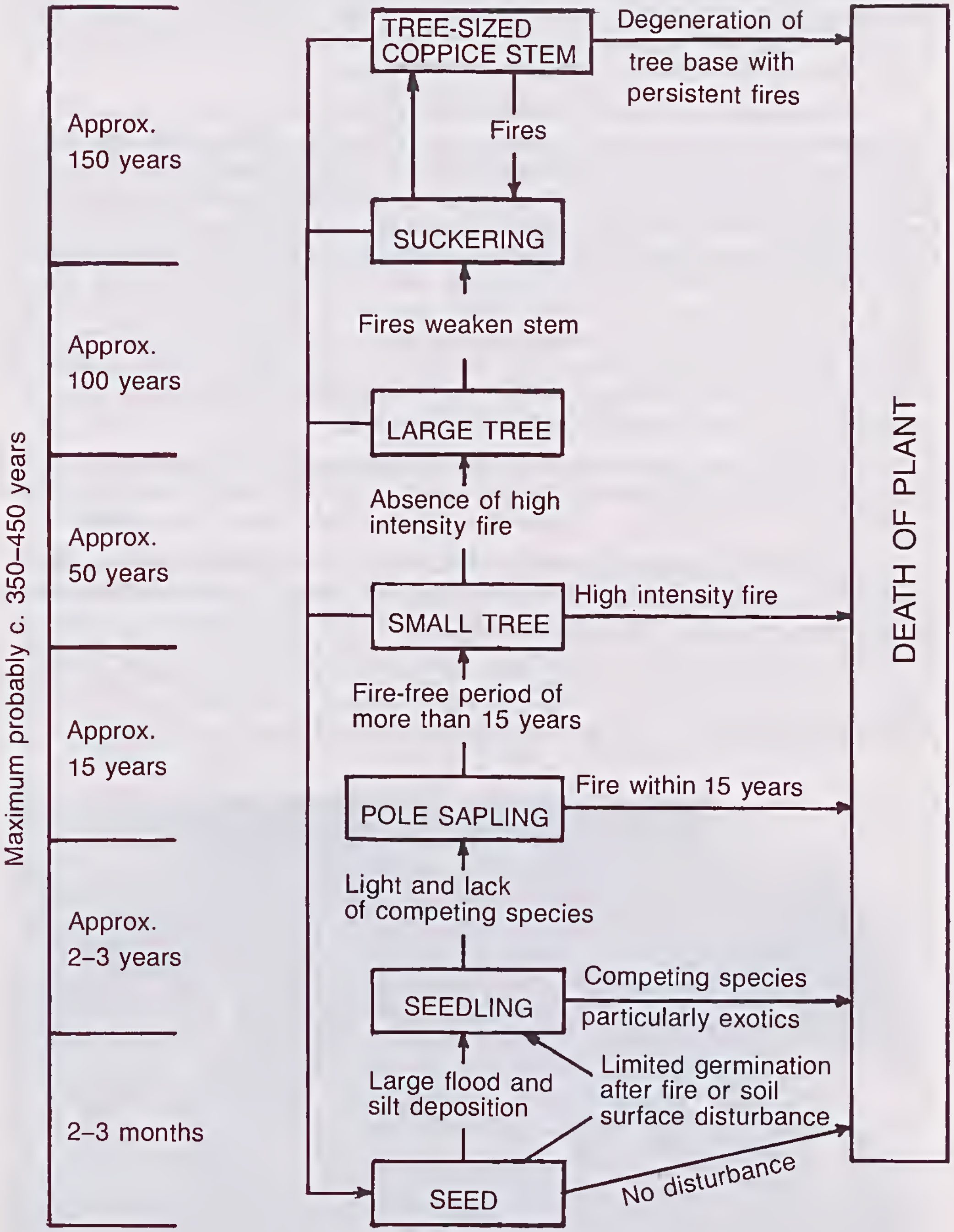

Maximum probably c. 350–450 years
Approx. 150 years
Approx. 100 years
Approx. 50 years
Approx. 15 years
Approx. 2–3 years
2–3 months
TREE-SIZED COPPICE STEM
Fires
SUCKERING
Fires weaken stem
LARGE TREE
Absence of high intensity fire
SMALL TREE
Fire-free period of more than 15 years
POLE SAPLING
Light and lack of competing species
SEEDLING
Large flood and silt deposition
SEED
Degeneration of tree base with persistent fires
High intensity fire
Fire within 15 years
Competing species particularly exotics
Limited germination after fire or soil surface disturbance
No disturbance
DEATH OF PLANT

Figure 7. Postulated life expectancy of *Eucalyptus benthamii* individual.

However, conditions have changed since 1900. The upper Nepean water storage dams, Cataract (completed 1907), Cordeaux (1926), Avon (1927) and Nepean (1935), have altered flood patterns and the amount of driftwood and debris piled up against the trunks of large trees has increased. This renders the trees more susceptible to bushfire damage as it increases the localized fire intensity at their bases; this in turn makes them more liable to subsequent collapse during storms.

The nutrient levels in sediment deposited by floods also appear to have changed. More fertilizer has been used for agriculture, and urban development, particularly near Camden, has expanded. The higher nutrient levels at Bents Basin are indicated by the abundance of exotic weeds (40 per cent of total species recorded). Agricultural weeds have probably been present for at least a century but there are also a number of exotics that would have originally been introduced to the Camden area as garden plants. Extensive gardens were developed around Camden last century (e.g. that of Sir William Macarthur at "Camden Park" and Sir William Macleay's "Brownlow Hill") and a great variety of exotic species were grown. The presence of exotic weed species such as *Ligustrum sinense* and *Araujia hortorum* poses a long-term threat as they tend to form a denser cover than the native species and prevent the establishment of the light-sensitive eucalypt seedlings.

The data from Kedumba indicate that regeneration of *E. benthamii* may occur following surface soil disturbance and be very successful where competition from other species is limited. Such regeneration has not been noted at Bents Basin.

The future for *E. benthamii* at Bents Basin appears to depend on the young trees that regenerated after the 1964 flood and that, provided they remain healthy, appear to have the potential to live for up to 200 years (Figure 8). At some time during that period it is likely that flood conditions will be suitable for the recruitment of another group of seedlings though these may have to be protected from competition by exotic species. The immediate threats to the young (1964) trees are land clearance (as some are in private ownership) and fire. The first may be best overcome by addition to the

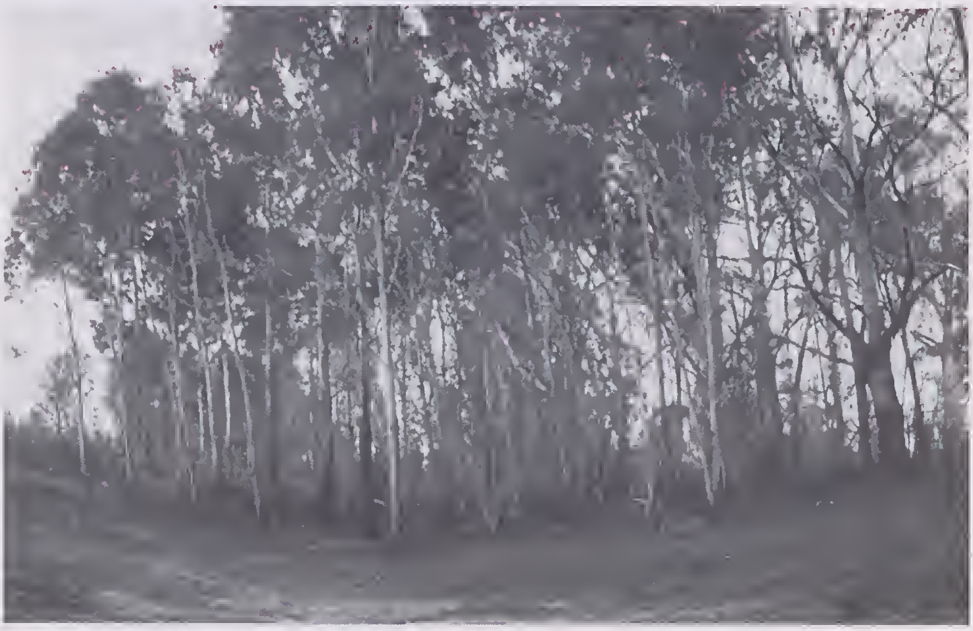


Figure 8. Stand of young trees of *E. benthamii* that germinated after the 1964 flood.

Bents Basin State Recreation Area, although the survival of the present population so far has been due to the special protection given to them by the landowner. It would be best to protect the stand from fire for at least 40 years and to remove flood debris from around the bases of individual trees to decrease potential damage from an unplanned fire.

ACKNOWLEDGMENTS

I wish to thank Mr R.S. Venables whose astute observations on the changing nature of the bushland at Bents Basin inspired this paper and without whose foresight and determination many of the trees would not have survived, Helen Bryant for her cheerful help in collecting the data, David Keith for preparation of the diagrams, and the Metropolitan Water Sewerage and Drainage Board for flood height data and access to catchment areas.

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Cunninghamia 1(3), 385–394 (1985)

OBSERVATIONS ON ALGAL FLORAS CLOSE TO TWO SEWERAGE OUTLETS

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(Accepted for publication 29.7.1983)

ABSTRACT

May, V. (National Herbarium of New South Wales, Royal Botanic Gardens, Sydney, New South Wales, Australia 2000) 1985. Observations on algal floras close to two sewerage outlets. Cunninghamia 1(3), 385–394. The algae present in the general area of planned sewerage outlets at an ocean (Ulladulla) and an estuarine (Plantation Point) headland, both south of Sydney, were recorded and changes in the floras and in the abundance of individual species were observed over a period of three to five years after the installation of the sewerage pipes. Species numbers declined after sewage began flowing, there were some floristic changes, and certain taxa showed changes in abundance. The same few species, namely *Gelidium pusillum, Ralfsia* sp. and *Ulva lactuca,* became important near both outlets, thriving on both sides and in the main part of the sewage flow. Both the extent and the degree of change caused by the sewage were greater at Ulladulla where the volume of sewage discharged was greater and its pre-treatment less thorough.

INTRODUCTION

Relatively little is known of changes induced in algal floras subjected to the influence of sewage. For Britain, Edwards (1972, 1975) reports only minor effects caused by sewage pollution, while in both Europe and America, Golubic (1970), Waite & Mitchell (1972), Littler & Murray (1975) and Murray & Littler (1977) report very great changes. Generally, the overall richness of the flora is reduced, and relatively few species increase in abundance. In the only previous local study, Borowitzka (1972) measured species diversity of intertidal macro-algae at three sites in the Sydney region that differed in levels of pollution from sewage. He showed that there was a decrease in the total number of algal species and in algal species diversity associated with a sewer outfall.

The proposed siting of sewerage outlets at Ulladulla and Plantation Point (Jervis Bay), some 200 km south of Sydney, stimulated the present studies of the macro-algae. The general intertidal flora of these headlands is described by May (1981). The observations reported now began before the sewerage works were installed and continued for three to five years. Species present in the intertidal zone near the outlet pipes were recorded and changes in the flora and in the abundance of individual species after the installation of the sewerage outfalls documented.

The study sites

Both study sites lie on the warm temperate east coast of Australia, in southern New South Wales. Ulladulla (35° 21′S, 150° 29′E) is some 40 km south of Plantation Point (35° 04′S, 150° 42′E; May, 1981). In each case, the general area selected for the outlet was a small natural indentation in the rock platform, 16 m wide at Ulladulla and 10 m wide at Plantation Point. The Ulladulla outlet is subject to extremely heavy seas, especially when southerly winds occur, while the outlet at Plantation Point, within Jervis Bay, is relatively wave-sheltered. The sewerage outlet pipe in each case was installed with the bottom of the pipe discharging near the interface of the tidal and sub-tidal zones. The sewage discharged contains low volume domestic effluent, after secondary treatment at Ulladulla and tertiary treatment at Plantation Point; the volume discharged is greater at Ulladulla (Table 1).

TABLE 1

Characteristics of sewage effluents*

Item	Ulladulla	Plantation Point
Treatment	Secondary	Tertiary
Average dry weather flow	$>3 \times 10^6$ L/day	0.6–1.0 × 10^6 L/day
Average biological oxygen deficiency (day 5)	20–40 × 10^{-3} g/L	5–10 × 10^{-3} g/L
Average non-filterable residue	20–30 × 10^{-3} g/L	10–20 × 10^{-3} g/L
Average pH	7.0–7.4	7.9–8.4

*Information supplied by Shoalhaven City Council, Nowra.

METHODS

The algal flora at the Ulladulla site was surveyed at monthly intervals between January 1974 and June 1979. The sewerage outlet was installed and functioning by September 1975. The study at Plantation Point started in March 1976 and continued until June 1979. Sewage began flowing from the outlet there in August 1976.

The areas below the vertical edge of the rock platforms and extending out as far as could be reached and/or seen at low tide were studied, a distance of about 16 m at Ulladulla, and about 6 m at Plantation Point. In both cases the overall vertical drop in the area of observation was just over one metre.

The species present were noted and their abundance assessed as "rare", "occasional", "common" or "very common". Observations were not possible at times because of the roughness of the sea or the timing of the low tides. Illness interrupted collecting during the 1976–77 period. Thus, at Ulladulla, there were 11 sets of records in 1974 (between January and December, 10 in 1975–76 (July–June), seven in 1977–78 (July–June) and eight in 1978–79 (July–June). The observations were made at Plantation Point on four dates in 1976 (between March and August), seven during 1977–78 (July–June) and nine during 1978–79 (July–June).

Between May 1978 (about 30 months after the commencement of sewage discharge) and June 1979 at Ulladulla, monthly records were kept of the relative proximity of various algae to the outlet pipe. The algal species were listed in order of occurrence from nearest the mouth of the sewerage outlet to some distance away. The sequence of algae nearest the outlet at Plantation Point was examined in the same way, regular observations being made from July 1978 (23 months after the outlet was opened) to June 1979.

Voucher specimens of all algae collected are lodged at the National Herbarium of New South Wales, Royal Botanic Gardens, Sydney (NSW). In the case of a common variable plant such as *Ulva lactuca,* detailed taxonomic study may indicate that a name covers a cluster of species. It is impossible to determine species within the Ectocarpales complex if the material is immature or infertile, so all records are grouped together in the tables under the "complex" name. All of the algae mentioned in the paper occur generally in the area of the respective headlands.

RESULTS

Algae occurring in the general area of the outlet at Ulladulla

Records of presence and of changes in abundance of the 37 species noted in the general area of the outlet at Ulladulla are given in Table 2. Following the opening of the sewerage outlet in September 1975 there was a decrease (from 31 to between 26

TABLE 2

Species recorded from the general area of the sewerage outlet at Ulladulla

Species	Changes in abundance			Periods of occurrence				
	Increase	No change	Decrease	1974	75–6	76–7	77–8	78–9
Acrotylus australis J. Ag.	—	x	—	x	x	x	x	x
Bangia fuscopurpurea (Dillw.) Lyngb.	x	—	—	—	x	—	x	x
Calothrix crustacea Schousb. & Thuret	—	x	—	—	x	—	—	—
Centroceras clavulatum (C. Ag.) Mont.	—	—	x	x	—	—	—	—
Ceramium sp.	—	—	x	x	x	—	—	—
Chaetomorpha aerea (Dillw.) Kuetz.	x	—	—	—	—	—	x	x
Chondria sp.	—	x	—	x	x	x	x	x
Cladophora repens (J. Ag.) Harv.	—	—	x	x	—	—	—	—
Codium cuneatum S. & G.	—	—	x	x	—	—	—	—
Corallina sp.	—	x	—	x	x	x	x	x
Corallina officinalis L.	—	x	—	x	x	x	x	x
Dictyota dichotoma (Huds.) Lamour	—	x	—	—	—	x	—	—
Encrusting red calcareous alga	—	x	—	x	x	x	x	x
Endarachyne binghamiae J. Ag.	—	—	x	x	x	x	x	x
Enteromorpha intestinalis (L.) Link.	x	—	—	—	x	—	x	x
Gelidium pusillum (Stackh.) Le Jol.	—	x	—	x	x	x	x	x
Gigartina aculeifera Zan.	—	x	—	x	x	x	x	x
Griffithsia monilis Harv.	—	—	x	x	—	—	—	—
Helminthocladia dotyi Wom.	—	—	x	x	—	—	—	—
Hildenbrandtia sp.	—	x	—	x	x	x	x	x
Jania sp.	—	—	x	x	—	—	—	—
Laurencia brongniartii J. Ag.	—	—	x	x	x	x	x	x
Laurencia filiformis (C. Ag.) Mont.	—	—	x	x	x	x	x	x
Lophosiphonia reptabunda (Suhr.) Cribb	—	x	—	—	x	—	—	—
Nemalion multifidum (W. & M.) J. Ag.	—	—	x	x	x	—	—	—
Padina fraseri (Grev.) Grev.	—	—	x	x	—	—	—	—
Phyllospora comosa (Labill.) C. Ag.	—	—	x	x	x	—	—	—
Plocamium cartilagineum (L.) Dixon	—	—	x	x	—	—	—	—
Porphyra columbina Mont.	x	—	—	x	x	x	x	x
Pterocladia capillacea (Gmel.) Born. & Thur.	—	x	—	x	x	x	x	x
Ralfsia sp.	x	—	—	x	x	x	x	x
Rhodymenia australis (Sond.) Harv.	—	—	x	x	—	—	—	—
Sargassum lophocarpum J. Ag.	—	—	x	x	x	x	x	x
Sargassum ?neurophorum J. Ag.	—	x	—	x	x	x	x	x
Splachnidium rugosum (L.) Grev.	—	—	x	x	x	—	x	—
Ulva lactuca L.	—	x	—	x	x	x	x	x
Wrangelia plumosa Harv.	—	x	—	x	x	x	x	x
TOTALS	5	15	17	31	26	19	22	21

and 19) in the total number of species recorded in any one year. Of the 31 species recorded in 1974, nine did not occur after the installation of the sewerage outlet (*Centroceras clavulatum, Cladophora repens, Codium cuneatum, Griffithsia monilis, Helminthocladia dotyi, Jania* sp., *Padina fraseri, Plocamium cartilagineum* and *Rhodymenia australis*) and a further three of the 31 were not recorded after the 1975–76 period (*Ceramium* sp., *Nemalion multifidum* and *Phyllospora comosa*). Splachnidium rugosum was present less often during the later years.

TABLE 3

Algae occurring nearest the sewerage outlet at Ulladulla*

Species	Frequency of occurrence (10 observation dates)		
	LHS	Centre	RHS
Gelidium pusillum	6	5	3
Ralfsia sp.	4	3	5
Ulva lactuca	5	2	7
Corallina officinalis	5	—	10
Acrotylus australis	1	—	3
Chrondria sp.	1	—	5
Encrusting red calcareous alga	4	—	3
Gigartina aculeifera[†]	7	—	3
Pterocladia capillacea	3	—	5
Hildenbrandtia sp.	1	1	1
Laurencia filiformis	2	—	—
Sargassum lophocarpum	1	—	—

*Species are listed in order of occurrence from nearest the mouth of the outlet.
[†] Found growing on *Pyura*.

Two species (*Bangia fuscopurpurea* and *Enteromorpha intestinalis*) appeared soon after the sewerage outlet was functional and remained throughout the period of study, whilst another, *Chaetomorpha aerea*, appeared later. Some species, including *Calothrix crustacea*, *Dictyota dichotoma* and *Lophosiphonia reptabunda*, appeared only in one year.

Eighteen species occurred throughout the study period; 12 of these showed no obvious change in abundance, while four others (*Endarachne binghamiae*, *Laurencia brongniartii*, *L. filiformis* and *Sargassum lophocarpum*) decreased in abundance and two (*Ralfsia* sp. and *Porphyra columbina*) increased.

Thus, the total number of species recorded in any one year decreased following the installation of the sewerage outlet, and also, of those species that occurred in two or more years, eight decreased in abundance whilst five increased.

Algae occurring nearest the sewerage outlet at Ulladulla

Table 3 gives the frequency of occurrence of species found closest to the outlet pipe between May 1978 (30 months after sewage started flowing) and June 1979. They are listed in order of occurrence from nearest the mouth of the outlet to some distance (1 to 2 m) away. Only 12 of the 37 species recorded in the general area have been observed close to the outlet. Nine of these occur commonly and three are less frequent; all must be considered tolerant of sewage effluent.

The three species found nearest to the sewerage outlet (*Gelidium pusillum*, *Ralfsia* sp. and *Ulva lactuca*) grew on both sides and also in the central area, receiving the full effect of the outfall. While *Ulva lactuca* was common on much of the headland prior to the installation of the outlet and retained its position near the outlet pipe throughout the period of study, *Ralfsia* sp. increased in abundance and *Gelidium pusillum* did not appear there until October 1978, but by June 1979 was the dominant plant nearest the outlet. Six other species occurred commonly on both sides of the outfall but not in the central area, and three others were recorded as infrequent (Table 3).

Algae occurring in the general area of the outlet at Plantation Point

Table 4 lists the 35 species noted in the area of the sewerage outlet at Plantation Point and the changes in their abundance over time. Too few collections were made

TABLE 4

Species recorded from the general area of the sewerage outlet at Plantation Point

Species	Changes in abundance			Periods of occurrence		
	Increase	No change	Decrease	1976	77–8	78–9
Amphiroa anceps (Lamour.) Decne.	x	—	—	—	x	x
Audouinella purpurea (Lightft.) Woelk.	—	(x)	—	—	(x)*	—
Ceramium sp.	—	—	x	x	—	(x)
Champia sp. (as recorded May *et al.*, 1978)	—	x	—	x	x	x
Cladophora repens (J. Ag.) Harv.	—	x	—	x	x	x
Codium lucasii Setchell	—	x	—	x	(x)	x
Colpomenia sinuosa (Roth.) Derb. & Sol.	—	x	—	x	x	x
Corallina officinalis L.	—	x	—	x	x	x
Cystophora moniliformis (Esper.) Wom. & Niz.	—	x	—	—	x	—
Dictyota dichotoma (Huds.) Lamour.	—	x	—	—	x	—
Ecklonia radiata (C. Ag.) J. Ag.	—	x	—	x	x	x
Ectocarpales complex	—	—	x	x	x	—
Encrusting red calcareous alga (as May, 1981)	—	x	—	x	x	x
Enteromorpha intestinalis (L.) Link.	—	x	—	x	x	x
Gelidium pusillum (Stackh.) Le Jol.	—	x	—	x	x	x
Griffithsia monilis Harv.	—	—	x	x	—	—
Hildenbrandtia sp.	x	—	—	—	x	x
Hormosira banksii (Turn.) Decne.	—	x	—	x	x	x
Laurencia filiformis (C. Ag.) Mont.	—	x	—	x	x	x
Lobophora variegata (Lamour.) Wom.	—	x	—	x	x	x
Lophosiphonia reptabunda (Suhr.) Cribb	—	—	x	x	—	—
Martensia elegans Hering	x	—	—	—	—	x
Microcoleus lyngbyaceus (Kuetz.) Crouan	—	(x)	—	—	—	(x)
Padina fraseri (Grev.) Grev.	—	x	—	x	x	x
Petrospongium rugosum (Ok.) S. & G.	—	x	—	—	x	—
Phyllospora comosa (Labill.) C. Ag.	—	(x)	—	—	—	(x)
Polysiphonia sp. (as recorded May *et al.*, 1978)	—	—	x	x	—	—
Porphyra columbina Mont.	x	—	—	—	(x)	x
Ralfsia sp.	x	—	—	—	x	x
Sargassum lophocarpum J. Ag.	—	x	—	x	x	x
Scytosiphon lomentaria (Lyngb.) C. Ag.	x	—	—	—	—	x
Sphacelaria tribuloides Menegh.	—	—	x	x	(x)	—
Stypopodium zonale (Lamour.) Pap.	—	(x)	—	—	(x)	—
Ulva lactuca L.	x	—	—	—	x	x
Zonaria turneriana J. Ag.	—	x	—	x	x	x
TOTALS	7	18 + (4)	6	21	22 + (5)	22 + (3)

*(X) = recorded outside of comparative period (March–August).

in 1976, before the opening of the outlet, to justify a comparison between the number of species occurring in each year. However, since pre-installation data are available for the autumn and winter months (March to August) of 1976, comparisons can be made for this period for each year: the resulting figures indicate that species numbers are almost constant (21, 22 and 22 respectively).

Some species, including *Griffithsia monilis, Lophosiphonia reptabunda* and *Polysiphonia* sp., were not recorded after the opening of the sewerage outlet, whilst others disappeared later (Ectocarpales complex and *Sphacelaria tribuloides*) or were less often present (*Ceramium* sp.). Others were noted for the first time after the sewage began flowing and either increased in abundance (*Amphiroa anceps,* *Hildenbrandtia* sp., *Porphyra columbina*, *Ralfsia* sp. and *Ulva lactuca*) or were recorded during one year only (*Cystophora moniliformis*, *Dictyota dichotoma*, *Petrospongium rugosum* in 1977–78; *Martensia elegans* and *Scytosiphon lomentaria* in 1978–79). Four taxa were noted only outside the periods of comparison (Table 4). Fifteen species occurred in all three years and did not change in abundance over that period.

Thus, the number of species recorded did not change greatly following the installation of the sewerage outlet and, although there were some floristic changes, the relative abundance of most of the taxa did not change.

Algae occurring nearest the sewerage outlet at Plantation Point

Table 5 gives the frequency of occurrence of species closest to the outlet pipe between July 1978 and June 1979 at Plantation Point. Seventeen of the 35 species recorded in the general area have been observed close to the outlet.

Six species occurred on both sides of the outlet and also in the central area, receiving the full effect of the outfall. Of these, *Corallina officinalis* was always present and abundant. *Enteromopha intestinalis* was very common but somewhat seasonal in occurrence, while *Gelidium pusillum* and *Ulva lactuca* were less often present. *Ralfsia* sp. and an encrusting red calcareous alga became more common towards the end of the observation period.

Three species (*Colpomenia sinuosa*, *Laurencia filiformis* and *Sargassum* sp.) were recorded from both sides of the outfall but did not occur in the central area; *Sargassum* sp. was the most common of these. A further eight species were noted as occasionally present close to the outlet (Table 5).

DISCUSSION

Effects of sewage

Comparison of the data from Ulladulla and Plantation Point suggests that the sewage has had a much greater effect on the algal flora at Ulladulla. The total number of species found in the general area of the outlet has been reduced rapidly and there have been considerable changes in individual species abundance at Ulladulla that are not shown to the same extent at Plantation Point.

Of the six species at Plantation Point recorded as receiving the full effect of the sewage outfall, only three were found in a similar position at Ulladulla (*Gelidium pusillum*, *Ralfsia* sp. and *Ulva lactuca*), although two others were present on both sides of the outlet there (*Corallina officinalis* and the encrusting red calcareous alga; Tables 3 and 5). At Plantation Point, *Ralfsia* sp. and the encrusting red calcareous alga are increasing in abundance, whilst at Ulladulla, *Gelidium pusillum* has become dominant. It seems likely that these differences represent a time-dependent adjustment to the effect of sewage, since the sewerage outlet has been functioning for a shorter period at Plantation Point that at Ulladulla.

Changes in the floras near the outlet pipes are not simple variations from year to year or from season to season. For example, *Gelidium pusillum* progressively decreased in frequency on both headlands between 1973 and 1979 (May, 1981) but became important near both sewerage outlets during the same period. Seasonal increases were shown by *Enteromorpha intestinalis* at both headlands and by *Ralfsia* sp. at Plantation Point, but changes were negligible in *Gelidium pusillum*, *Corallina officinalis*, *Ulva lactuca* and the encrusting red calcareous alga. Changes in season

TABLE 5

Algae occurring nearest the sewerage outlet at Plantation Point*

Species	Frequency of occurrence (9 observation dates)		
	LHS	Centre	RHS
Corallina officinalis	9	6	9
Encrusting red calcareous alga	5	1	3
Enteromorpha intestinalis	4	2	3
Gelidium pusillum	1	1	1
Ralfsia sp.	2	2	5
Ulva lactuca	2	1	1
Amphiroa anceps	3	—	—
Colpomenia sinuosa	1	—	3
Laurencia filiformis	2	—	2
Sargassum sp.	6	—	9
Zonaria turneriana	3	—	—
Cladophora repens	2	—	—
Codium lucasii	1	—	—
Hildenbrandtia sp.	1	—	—
Hormosira banksii	1	—	—
Martensia elegans	—	—	1
Microcoleus lyngbyaceus	—	1	—

*Species are listed in order of occurrence from nearest the mouth of the outlet.

had little or no effect on the distribution and abundance of the species nearest the sewerage outfall.

The greater effect of the sewage at Ulladulla compared with that at Plantation Point correlates with the marked difference in the amount and type of sewage present. The sewage at Plantation Point received tertiary treatment, compared with only secondary at Ulladulla, and the average dry-weather flow, the non-filterable residue and the biological oxygen demand were lower at Plantation Point than at Ulladulla (Table 1).

At Ulladulla the number of species present decreased rapidly soon after the sewage began flowing and there were further reductions within 12 months of the outlet becoming functional. Also, a number of species decreased in abundance over time, whilst some others increased. The changes in abundance of some species, at least, appear to be due to the effects of the sewage, as their abundance rating was unchanged in areas not affected by sewage over the same period (May, 1981). At Plantation Point there were comparatively few losses immediately after the sewage began and even less later. Thus, even though the effluent would generally be more aerated and more readily dispersed by water movement at Ulladulla (due to its position on an ocean rock platform) the effect of the sewage was much more obvious there. It seems that the amount and type of sewage discharged was more significant than the nature of the outfall site.

Comparison with other studies

Edwards (1972) reported a small effect of sewage within an estuary and he later stated (Edwards, 1975) that general pollution had little effect on species diversity on open coasts where there is good water circulation. While this may apply for areas some distance away from the outlet, the reduction in numbers of species and the changes in abundance in certain taxa near the sewerage outlet recorded here are more in accord with the results of Golubic (1970). For the Mediterranean coast he reported that, while the numbers of species decreased with organic pollution, the number of individuals of the remaining species increased until only two became dominant (species of *Ulva* and *Hypnea*) and later even these disappeared. His work on the Adriatic coast (Golubic, 1970) showed that increased pollution led to increased amounts of *Ulva lactuca* and *Codium tomentosum.* Elsewhere, Waite & Mitchell (1972) reported that fertilization by sewage can lead to a diverse flora of an estuary being reduced to a single dominant, *Ulva,* and Ranwell (1972) noted that extensive growths of *Enteromorpha* occurred where sewage accumulated. Littler & Murray (1975) reported that a Californian area subjected to low-volume domestic sewage was dominated by "blue-green algae" and by *Gelidium pusillum, Ulva californica* and small *Pterocladia capillacea.* In a later paper, the species recorded as most abundant "in the upper- and mid-littoral [zones] of the outfall region" were "blue-green algae", Ectocarpaceae, colonial diatoms, *Ulva californica* and *Gelidium pusillum* (Murray & Littler, 1977).

The importance of *Corallina officinalis* in the present study is in accord with Kindig's (1977) comment on the remarkable dominance of coralline algae in areas of high sewage concentration and in contrast to that of Brown *et al.* (1977) who found that the growth of coralline algae was "significantly inhibited by a medium enriched with orthophosphate"; the level of enrichment was probably the significant difference.

Borowitzka (1972) listed *Enteromorpha* spp. and *Chaetomorpha aerea* as the two taxa dominant near the sewerage outlets at North Head, Sydney, and a further seven species as present in the general vicinity of the outlets (*Ulva* sp., *Corallina* sp., *Petalonia* (*Ilea*) *fascia, Jania* sp., *Pterocladia pinnata, Porphyra columbina* and *Centroceras clavulatum*). All of these except *Petalonia* are recorded in the general area of the ocean outlet at Ulladulla, but the dominant species (*Gelidium pusillum, Ralfsia* sp. and *Ulva lactuca*) differ, and of the others, only *Corallina officinalis* and *Pterocladia capillacea* are important close to the outlet pipes (Table 3). The differences may be linked with the length of time the sewerage outlet has been operating or with the high levels of detergents present in the sewage released at Sydney compared with the southern site, but further investigation of the differences are needed.

CONCLUSIONS

This study has examined the changes occurring in algal floras and in the abundance of individual algal species subjected to the influence of sewage over a period of five years at an ocean headland, Ulladulla, and three years at an estuarine headland, Plantation Point, both on the South Coast of New South Wales.

At Ulladulla there was a marked and rapid decrease in the total number of species recorded in any one year in the general area of the outlet and also some changes in floristics and in abundance (both decreases and increases) of certain species. At Plantation Point some similar changes were noted but these were less marked.

Close to the sewerage outlets at each site there was a great decrease in species numbers and in each case a few species became abundant, growing on both sides and in the main path of the sewage flow. Three species, *Gelidium pusillum, Ralfsia* sp. and *Ulva lactuca,* occur in these conditions at both outlets, despite one outlet being oceanic and the other estuarine. Two other species, *Corallina officinalis* and an encrusting red calcareous alga, are also found in the immediate vicinity of the outlets at each site.

The reduced number of species in the general area and the lower number of species dominant nearest to the sewerage outlet at Ulladulla compared with Plantation Point suggest that the effects of the sewage are much greater at Ulladulla. It is considered that the volume of sewage discharged and the nature of the pretreatment of the effluent are important factors and are more significant than is the nature of the outlet site. The longer period that the sewerage outlet at Ulladulla has been functioning compared with that at Plantation Point may also be important.

Comparisons with other studies indicate that only a few genera, and often the same few, are important at sites affected by sewage (*Corallina, Codium, Enteromorpha, Ulva, Gelidium* and *Pterocladia*) and in some cases even the same species, such as *Ulva lactuca* and *Gelidium pusillum;* they indicate the widespread nature of the tolerance to sewage amongst diverse groups of algae.

Other observations suggest that the effects noted until now within a short distance of the sewerage outlets are likely to extend further after a longer period of influence.

ACKNOWLEDGMENTS

I am grateful to Mr R.T. Knowles the Shoalhaven City Council, Nowra, for information about the sewage at both outfalls; also to Dr Leon Collett, formerly of N.S.W. State Fisheries, now of the Marine Pollution Studies Group, Victoria, for advance information regarding the siting of these outfalls.

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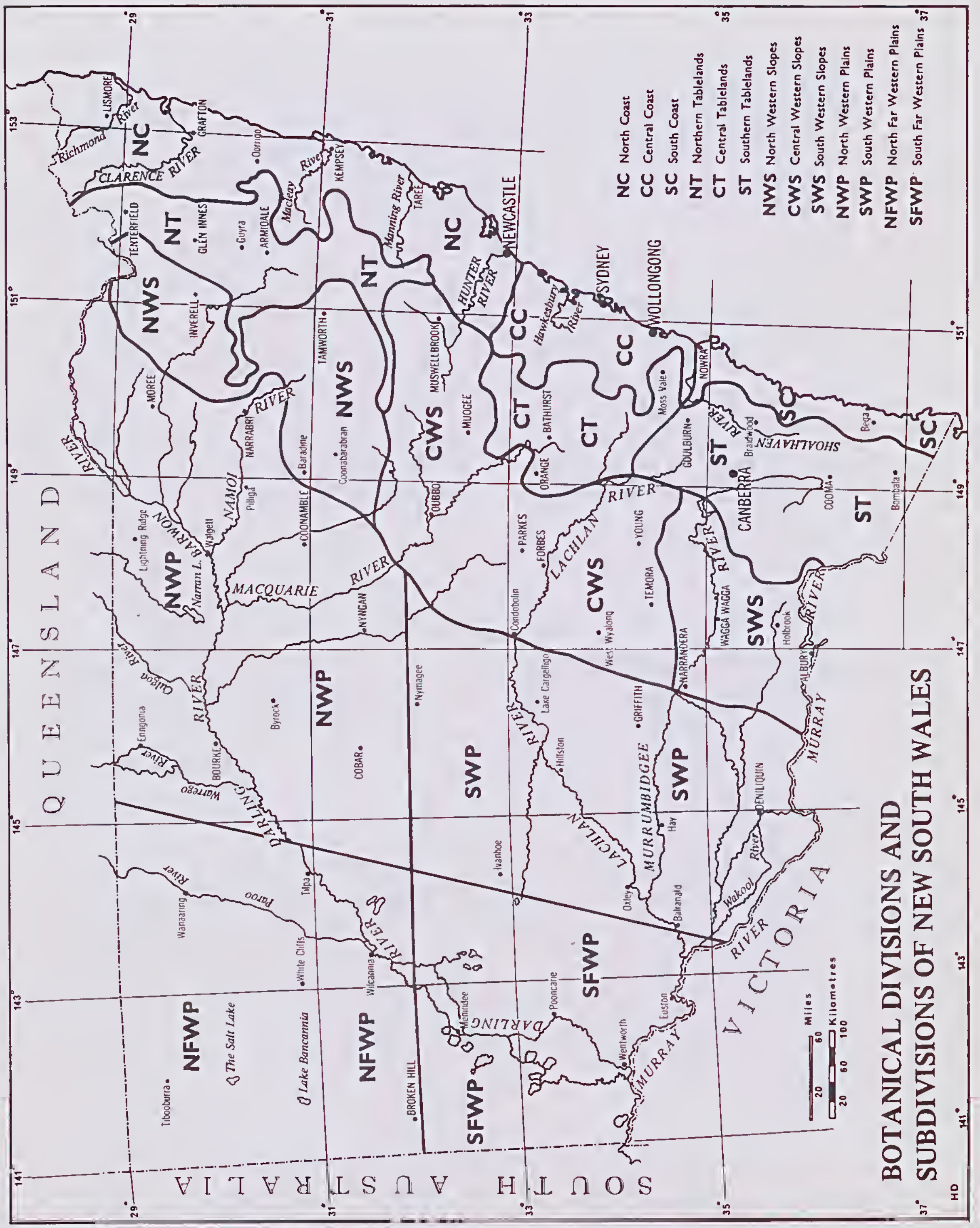
CORRIGENDUM

J. Pickard (1983). Vegetation of Lord Howe Island. *Cunninghamia* **1(2),** 133–266.

All basal area data are incorrect due to an error in converting from imperial to metric units. All values should be multiplied by 0.05.



For explanation and description of the Botanical Divisions and Subdivisions of New South Wales see Anderson, R.H. (1961). Introduction. *Contr. New South Wales Natl. Herb. Fl. New South Wales* Nos. 1–18, pp. 1–15.

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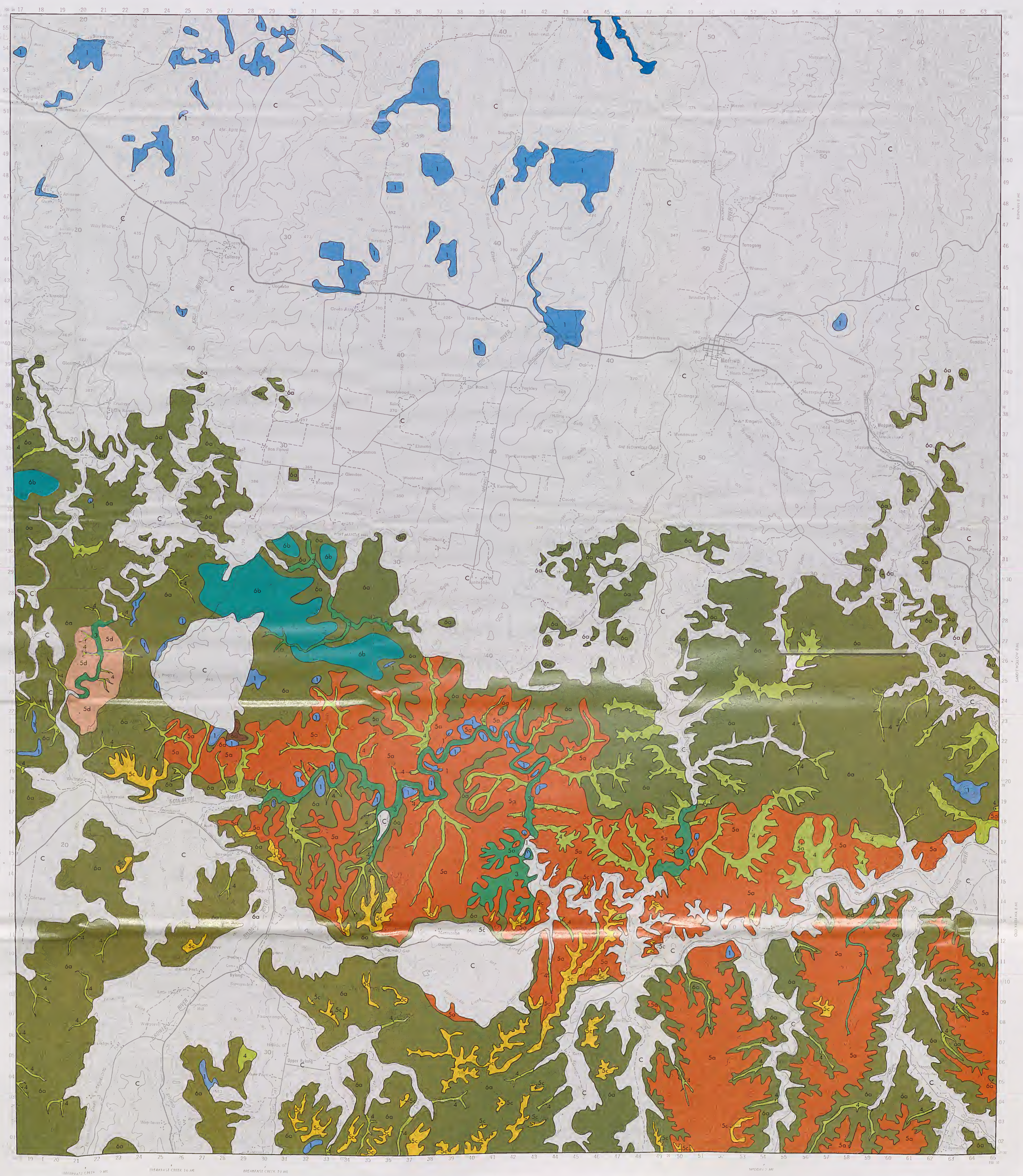
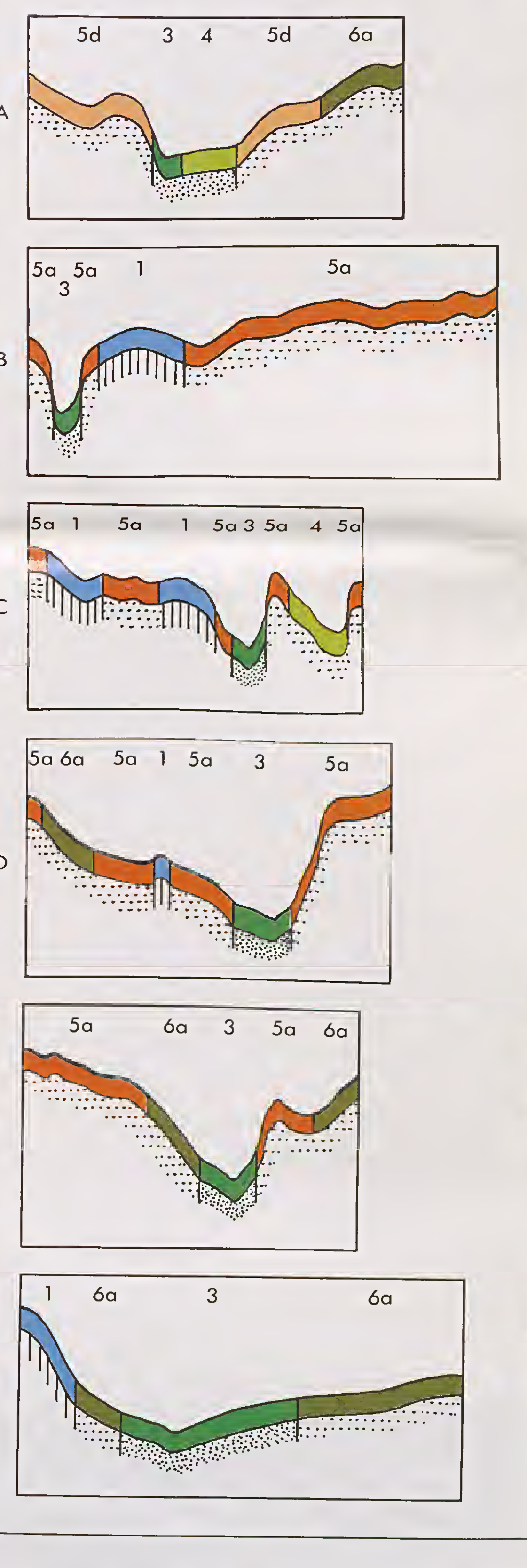
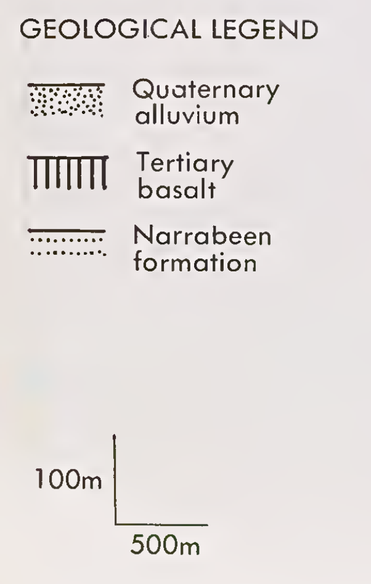


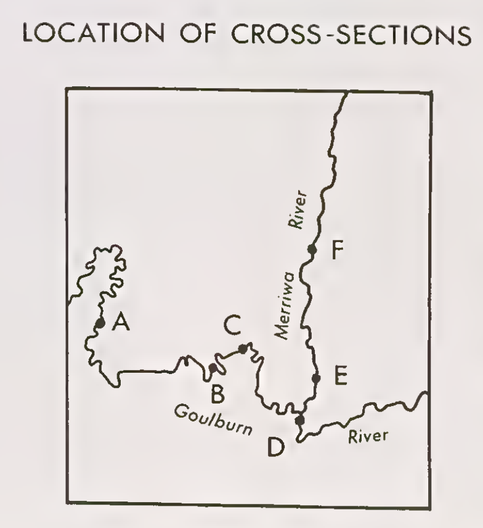
PLANT COMMUNITY DESCRIPTIONS

	STRUCTURE	MAIN SPECIES	GEOLOGY	HABITAT
1	Open woodland	*Eucalyptus albens,* *E. melliodora,* *Brachychiton populneus.*	Tertiary basalt	Foothills, Liverpool Range; Merriwa Plains.
	Open woodland	*E. albens/* *E. moluccana,* *E. dealbata, E. albens,* *Callitris endlicheri.*		Perched remnants, near Goulburn River.
	Open woodland	*E. albens*		Perched remnants, Wollemi N.P.
	Open woodland	*E. moluccana,* *Acacia* sp.aff. *decurrens.*		Mt. Dangar.
2	Woodland	*Eucalyptus melliodora,* *E. laevopinea,* *E. viminalis,* *Allocasuarina torulosa.*	Tertiary basalt	Liverpool Range.
3	Woodland/ Open woodland	*Eucalyptus crebra,* *E. melliodora,* *E. blakelyi,* *Angophora floribunda,* *Casuarina cunninghamiana.*	Quaternary alluvium	Broad river flats.
	Woodland/ Open woodland	*E. albens/* *E. moluccana,* *Callitris endlicheri,* *Brachychiton populneus.*		River flats with basalt influence.
4	Woodland	*Eucalyptus punctata,* *Acacia linearifolia,* *E. dawsonii.*	Quaternary alluvium, colluvium	Smaller valleys, gullies.
5a	Woodland/ Open woodland	*Eucalyptus caleyi,* *Acacia doratoxylon,* *E. trachyphloia,* *A. crassa.*	Narrabeen formation	Thin soils, ridge-tops near mature valleys.
5b Mapped with 5a or 5c	Low shrubland	*Philotheca salsolifolia,* *Baeckea cunninghamii,* *Calytrix tetragona,* *Phebalium squamulosum,* *Leptospermum parvifolium.*		Skeletal soils, ridge tops above cliff-lines.
5c	Low Open woodland	*E. dwyeri, E. oblonga,* *E. caleyi, E. punctata,* *Acacia doratoxylon,* *Callitris endlicheri.*		Thin soils on ridge-tops; higher elevations; exposed sites.
5d	Low Open woodland	*E. trachyphloia,* *E. rossii.*		Fine textured sandy soils.
6a	Woodland/ Open woodland	*Eucalyptus fibrosa,* *Callitris endlicheri,* *E. punctata.*	Narrabeen formation	Talus slopes.
6b	Woodland	*E. crebra,* *E. sideroxylon,* *E. punctata,* *E. fibrosa.*		Deeper sandy soils, plateau tops.
6c Mapped with 6a or 6b	Open shrubland	*Melaleuca uncinata,* *Allocasuarina* sp. aff. *distyla,* *Acacia triptera,* *Kunzea ambigua.*		Poorly drained clayey soils, plateau tops.
6d	Woodland	*E. maculata,* *E. crebra,* *Callitris endlicheri.*		Sandy soil, basalt influence.
C	Cleared land with occasional remnant trees.			

REPRESENTATIVE VALLEY CROSS-SECTIONS, SHOWING PLANT COMMUNITIES, LANDFORM AND SURFACE GEOLOGY







INDEX TO ADJOINING MAPS

COOLAH 8834	BLACKVILLE 8934	MURRURUNDI 9034
GULGONG 8833	MERRIWA 8933	MUSWELLBROOK 9033
MUDGEE 8832	MOUNT POMANY 8932	HOWES VALLEY 9032

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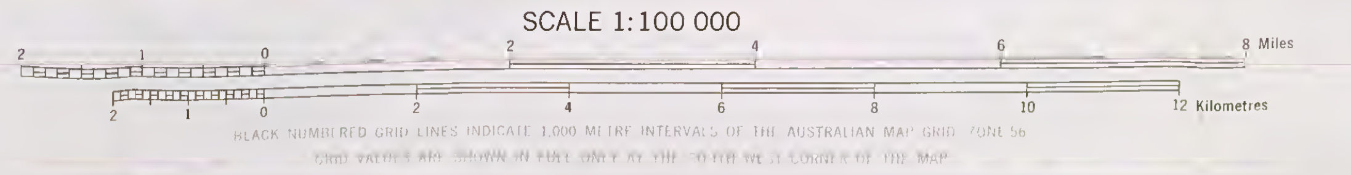

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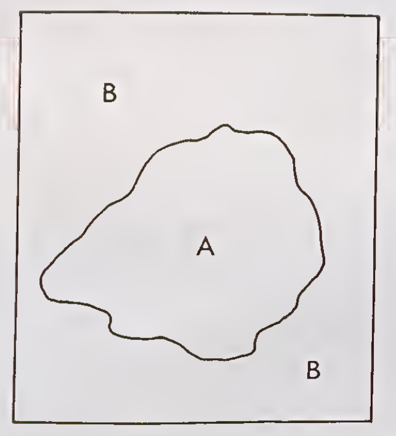

A	Air photo interpretation, general reconnaissance, and detailed quantitative data collection.
B	Air photo interpretation, with limited reconnaissance.

VEGETATION
OF THE
MERRIWA AREA
New South Wales

R. McRae
and
M. Cooper

Compiled and Prepared at the
NATIONAL HERBARIUM OF NEW SOUTH WALES,
ROYAL BOTANIC GARDENS, SYDNEY
1983

To accompany CUNNINGHAMIA VOLUME 1, NUMBER 3, 1983

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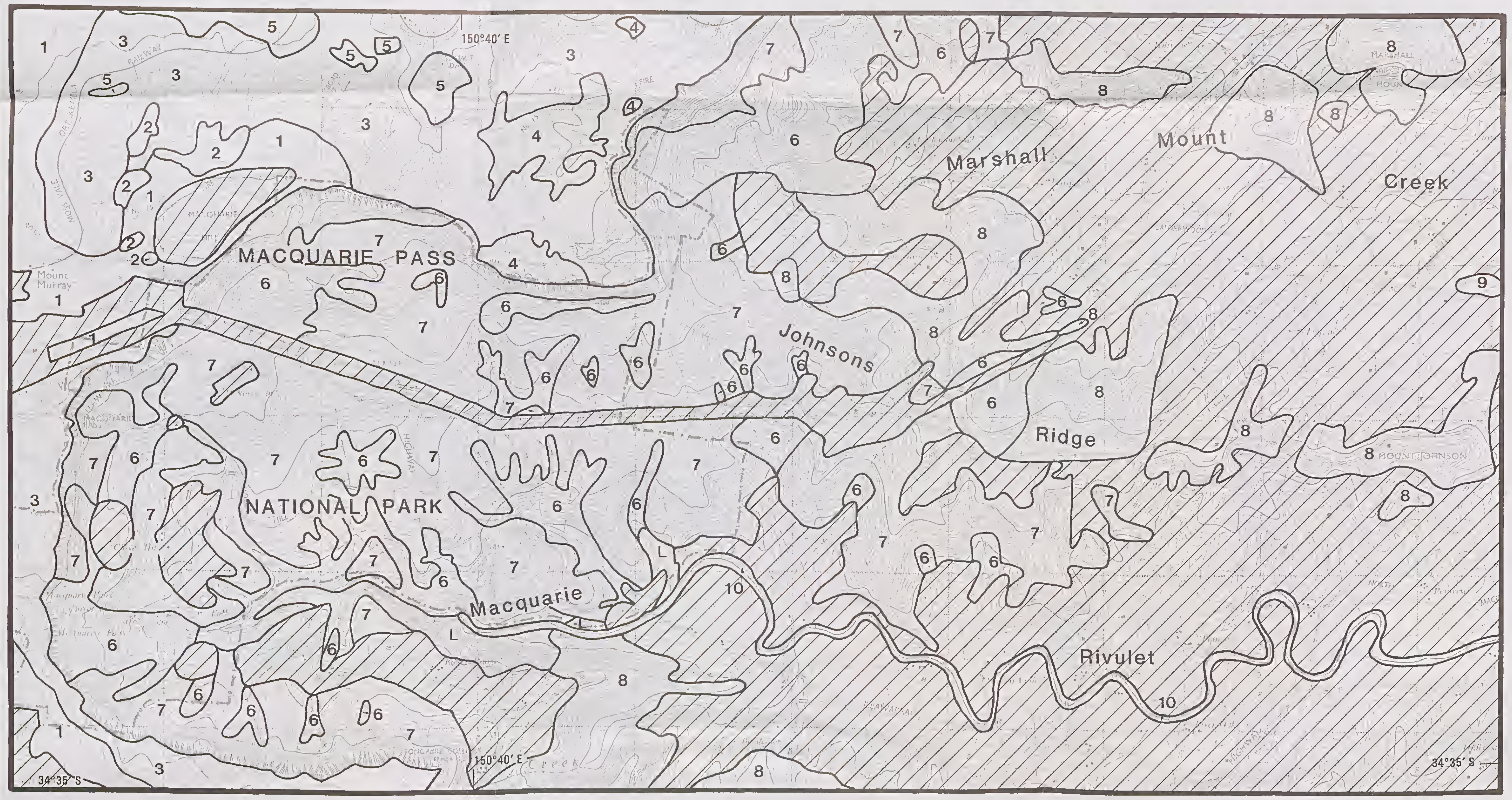
VEGETATION OF MACQUARIE PASS

H. FALLDING and J.S. BENSON



N

Vegetation Map   Scale 1:25 000

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km

Topographic base map from ROBERTSON 9028-IV-N
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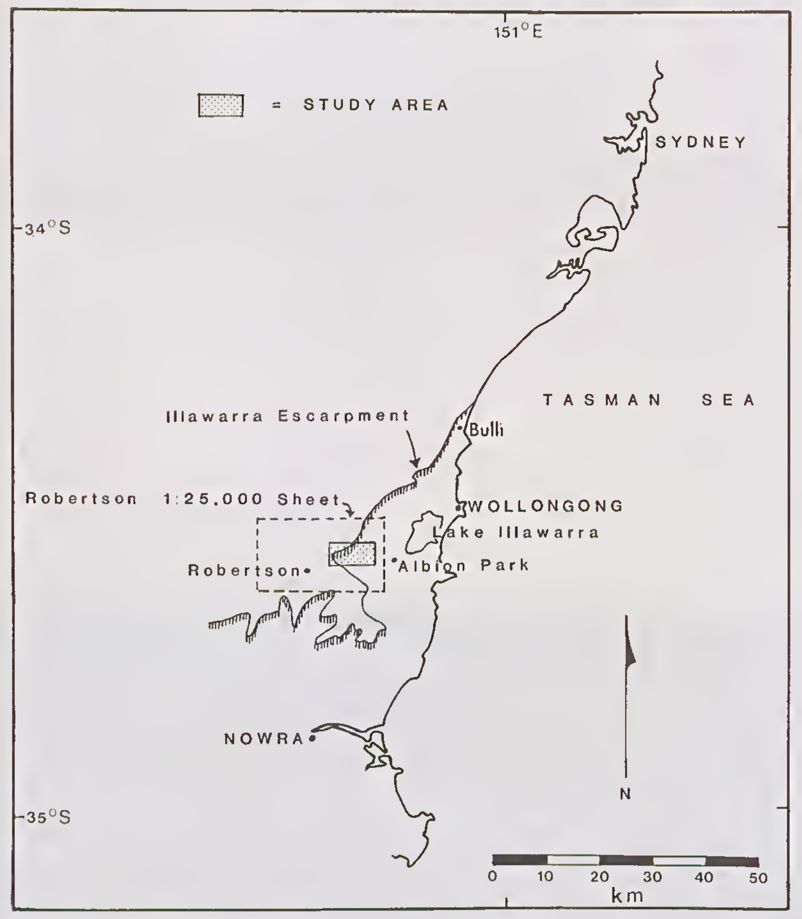
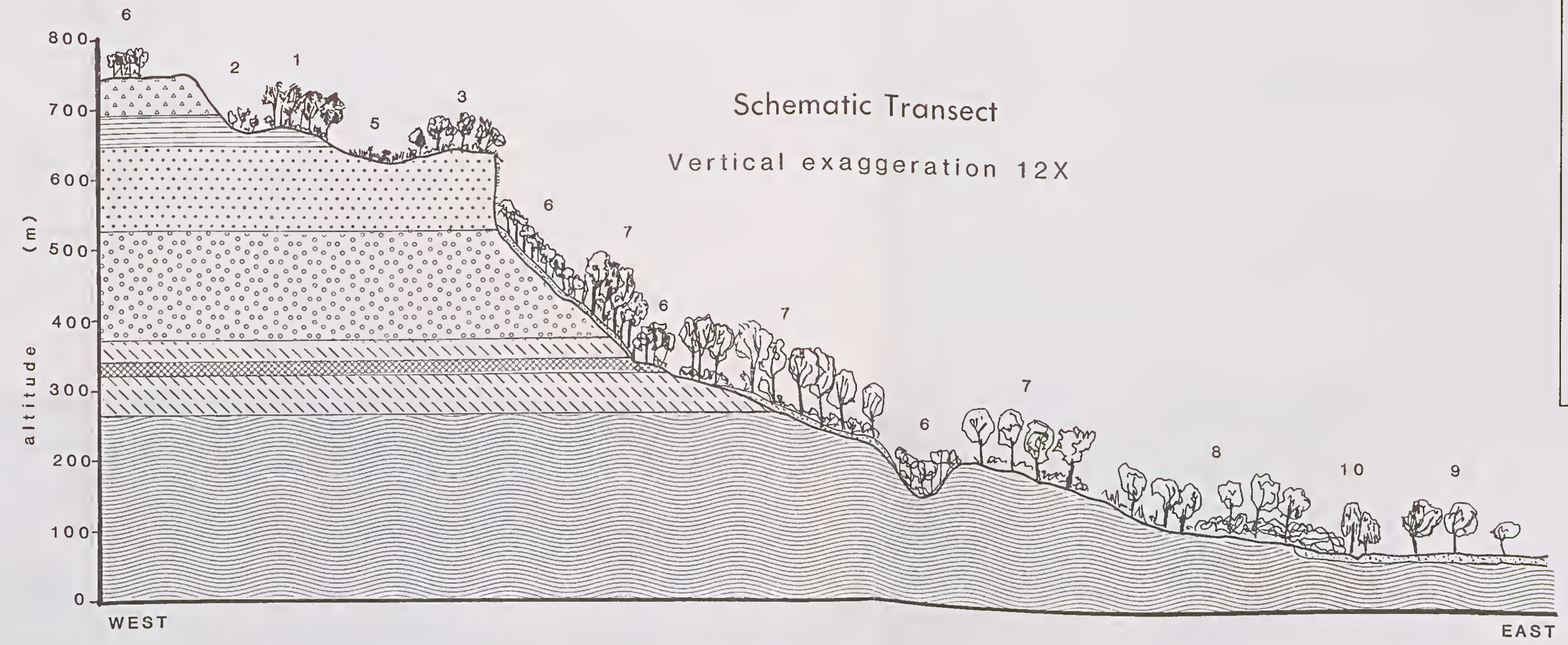
6 Plant community numbers
L Areas dominated by ***Lantana camara***
▨ Cleared areas
Plant community boundaries
-·-·- National Park boundary

VEGETATION OF MACQUARIE PASS
H. FALLDING & J. S. BENSON




Schematic Transect

Vertical exaggeration 12X

Relationship between Plant Communities, Geology and Topography

GEOLOGY		VEGETATION		
Key	Name and Rock Type of Stratum	Comm. No.	Structure	Dominant Species
△	Robertson Basalt Basalt and basanite	6	CLOSED-FOREST Warm Temperate/ Cool Temperate Rainforest	*Doryphora sassafras*, *Quintinia sieberi*, *Ceratopetalum apetalum*, *Rapanea howittiana*, *Polyosma cunninghamii*
▤	Wianamatta Group Mudrock and lithic sandstones	1	OPEN-FOREST	*Eucalyptus obliqua*, *E. cypellocarpa*, *E. radiata*
		2	OPEN-SCRUB	*Eucalyptus ovata*, *Melaleuca linariifolia*, *Acacia longifolia*, *Pultenaea blakelyi*, *Leptospermum flavescens*
⁘	Hawkesbury Sandstone Quartzose sandstone, some mudrock interbeds	3	LOW OPEN-FOREST to OPEN-FOREST	*Eucalyptus sieberi*, *E. smithii*, *E. piperita* ssp. *urceolaris*, *E. ligustrina*
		4	Shrub Communities	
		A	OPEN-SCRUB	*Melaleuca squarrosa*, *Leptospermum* spp., *Banksia ericifolia*
		B	OPEN-HEATH	*Banksia ericifolia*, *Hakea teretifolia*, *Eucalyptus stricta*, *Banksia paludosa*
		C	LOW SHRUBLAND	*Eucalyptus stricta*, *Leptospermum attenuatum*, *Acacia obtusifolia*, *Banksia ericifolia*
		5	SEDGELAND	*Lepyrodia anarthria*, *Leptocarpus tenax*, *Lepidosperma laterale*
○	Narrabeen Group Quartz and lithic sandstones, mudrock	6	CLOSED-FOREST	
		i	Warm Temperate Rainforest (Gullies at lower altitudes)	*Ceratopetalum apetalum*, *Daryphora sassafras*, *Cryptocorya glaucescens*, *Acmena smithii*, *Polyosma cunninghamii*, *Dendrocnide excelsa*
		ii	Warm Temperate/ Cool Temperate Rainforest (at higher altitudes only)	*Doryphora sassafras*, *Quintinia sieberi*, *Ceratopetalum apetalum*, *Rapanea howittiana*, *Polyosma cunninghamii*, *Eucryphia moorei*
		7	TALL OPEN-FOREST to OPEN FOREST	Dominant spp. vary with substrate and altitude; *Eucalyptus smithii*, *E. fastigata*, *E. quadrangulata*, *E. muellerana*
▧	Illawarra Coal Measures Mudrock, claystone, coal, latite	6	CLOSED-FOREST	see Narrabeen Group 6i
		7	TALL OPEN-FOREST to OPEN FOREST	see Narrabeen Group 7
▩	Minnamurra Latite Member	6	CLOSED-FOREST Warm Temperate/ Subtropical Rainforest	*Doryphora sassafras*, *Ceratopetalum apetalum*, *Livistona australis*
▤	Shoalhaven Group Volcanic to fine sandstone	6	CLOSED-FOREST	see Narrabeen Group 6i
		8	OPEN-FOREST to LOW OPEN-FOREST Escarpment Foothills	*Eucalyptus tereticornis*, *E. globoidea*, with *E. saligna/batryaides* in moister gullies
		9	WOODLAND to OPEN-FOREST Coastal Plain	On rises - *Eucalyptus longifolia*, *E. eugenioides*, *Angophora floribunda*, *Melaleuca decora* In depressions- *E. amplifolia*, *Melaleuca styphelioides*, *Casuarina glauca*
		10	RIVERINE WOODLAND	*Casuarina cunninghamiana*

Compiled and prepared at the National Herbarium of New South Wales, Royal Botanic Gardens, Sydney. 1983

To accompany CUNNINGHAMIA Volume 1 Number 3

Produced and Printed by the Central Mapping Authority of New South Wales, Panorama Avenue, Bathurst. 1983

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ISSN 0727–9620